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Stress detection utilizing the electroencephalogram.

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THESIS

STRESS DETECTION
UTILIZING THE
ELECTROENCEPHALOGRAM

by

Harold Jean Fricke, Jr.

March 1977

Thesis Advisor: G. Marmont

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STRESS DETECTION UTILIZING THE ELECTROENCEPHALOGRAM

by

Harold Jean Fricke, Jr.
Lieutenant Commander, United States Navy
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

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ABSTRACT

A method of stress detection utilizing the electroencephalogram is presented. Limited discussion on nerve cells and some physiological aspects of stress are discussed. Considerable data is presented which supports a stress detection theory. Methods of stress inducement utilized and the conduct of an electroencephalogram are described. Conclusions and recommendations for future research are submitted.

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Acknowledgements

It is only with deep respect and gratitude that the unwavering patience and guidance of Dr. George Marmont is acknowledged. The short two years of association with him have made possible attainment of an education much broader in scope than otherwise possible. His continual prodding and long hours of work made completion possible in the allotted time. His principle, succinctly expressed as "Only nothing should be transparent to the user" is now indelibly inscribed in the author's thought pattern and indeed is one which Professor Marmont teaches through exemplary action.

Very few accomplishments are achieved individually in the Bio Lab. Most are products of a tremendous team effort and the work of all who pass through this program assist future students to proceed onward. This thesis is possible due to help from the present team members: Lt Dan Lashbrook; and Lt Billy Cornett. Their cooperation as subjects and critics has contributed significantly to this research.

The quiet understanding and wisdom of my wife Linda must be especially acknowledged. The disappointments and long hours of studies which she has endured with never a word of complaint, and the happiness and accomplishments she has shared have been major contributions to my education and career and words cannot properly express my gratitude to her.

I. INTRODUCTION

The study of Bioengineering in general and the electroencephalogram (EEG) in particular affords an engineer the opportunity of immediately applying real world criteria to a real world situation. In recent years the understanding of the human brain has increased in priority and indeed is a necessity if man is to continue to develop technologically while maintaining a peaceful world environment. Present day research in bioengineering is somewhat sparse when compared to research carried out to develop machinery for man to operate, yet it seems an understanding of the operator would be just as important and should be a parallel effort. If, for instance, the electrochemical process of memory were thoroughly understood, it may well be that education could be dramatically accelerated through more appropriate means. Speculation of the benefits to be derived from a complete understanding of the human brain is endless, and an important starting point is the detection of stress which affects skilled motor control activity.

II. BACKGROUND

A. PRELIMINARY

Very little research has been conducted in an attempt to define stress through an EEG. It is postulated, however, that definitive patterns exist when an individual is experiencing stress and that the presence and degree of stress may someday be measured by presence and amplitude of such a pattern. Military applications of such knowledge are vast with most immediate usefulness in the field of aviation.

B. THE EXPERIMENT

The problems associated with inducing stress in an individual are as numerous as the individuals themselves. How to measure envoked stress and its impact on performance are questions which can be answered only after the presence of stress is detected, which is the primary subject of this thesis. It was thus decided that the application of stress tactics would be as uniform as possible, recognizing that the amount of stress varied not only among subjects but from hour to hour with one subject. Methods utilized are discussed later. Comparison runs were consistently conducted without stress, then with stress tactics employed. Subject comments were solicited and weighted in conclusions obtained.

C. ENVIRONMENT

When researching particular aspects of an EEG, it is important that responses be confined to the ones of interest as much as possible. Since human sensors cannot be arbitrarily switched off or easily isolated, every effort was made to ensure that no irrelevant disturbance excited these sensors. Subjects were placed in a small room enclosed by fine wire mesh. Lights were extinguished except for those essential in the tasking. Noise was maintained at a minimum, and any conversation outside the room was covered by the nearly white noise generated by the PDP 11/40 cooling fans. Subjects were seated comfortably in an easy chair and were allowed to perform tasks either in an upright position or slightly reclined. All these efforts were in an attempt to avoid myograms and aurally and visually evoked responses.

D. THE AUTHOR'S CONTRIBUTION

The author was actively engaged as a member of the Bio Team for nearly two years. The stress tactics, associated circuitry, and other less significant accomplishments were of the author's contribution. The number of hours of research and time expended in analysis, both as a team member and individually are quite significant. Finally, all the equipment in the laboratory is maintained by members of the team, and the author has contributed in this area as well.

E. A DISCUSSION OF NERVE CELLS

A nerve cell or neuron is a single cell which differs from many other type cells in several ways, and most importantly by being "excitable". It is capable of transmitting and receiving electrochemical impulses along its membrane, and is the vehicle through which man is able to move, sense, and survive. These impulses along the membrane are produced by a change in resting membrane potential. This potential is caused by an excess number of negative ions accumulated along the inner cell surface and a corresponding number of positive ions accumulated just outside the membrane surface. Development of an action potential is caused by an active transport of ions through the membrane and a diffusion of ions through the membrane due to concentration differences.

While completely undisturbed, the nerve membrane remains at a resting potential of approximately -85 millivolts. However, any disturbance which changes permeability of the membrane is likely to cause a series of rapid changes called the action potential. If potential is raised to a threshold, the nerve "fires" and an impulse travels along the membrane, and if threshold is not reached, the membrane returns to resting potential.

Figure 1 graphically displays these changes in potential. The absolute refractory period is one in which the nerve cannot be further excited, and the relative refractory period is one in which it is not as easily excited. Nerve impulses are of constant amplitude, but can vary in the number per second. Areas of the curve labelled depolarization and repolarization refer to diffusion of

sodium ions to the nerve interior and diffusion of potassium ions from the nerve interior respectively. Not previously mentioned is the fact that there is a diffusion of sodium ions outward and potassium ions inward through sodium and potassium pumps that constantly work to maintain a proper balance of these ions.

Nerves are joined together by junctures called synapses. Figure 2 shows a greatly simplified motoneuron joined by two other neurons-one excitatory and one inhibitory. Actually there are hundreds of other neurons joining this one motoneuron, all transmitting their own frequency coded message. A neuron is either excitatory or inhibitory and cannot be both, although each is capable of receiving either type signal.

There are other characteristics which bear mentioning here. Synaptic transmissions are rectified due to the release of a chemical transmitter at the terminal ends of the incoming nerve fiber. If the chemical transmitter is excitatory, the membrane of the receiving neuron is depolarized whereas if it is inhibitory it is hyperpolarized. The axon hillock algebraically sums all inputs (excitatory and inhibitory). If this sum reaches threshold, then a new action potential is set- up at the axon hillock and propagates out to the next units in the circuit chain. Figure 1 shows the way the excitatory and inhibitory effects may be summed. There is a spacial facilitation for simultaneous inputs from several axons and a temporal facilitation wherein the incoming impulses are offset in time, but follow one another fairly closely.

Figures 3 and 4 depict some arrangements of these junctures.

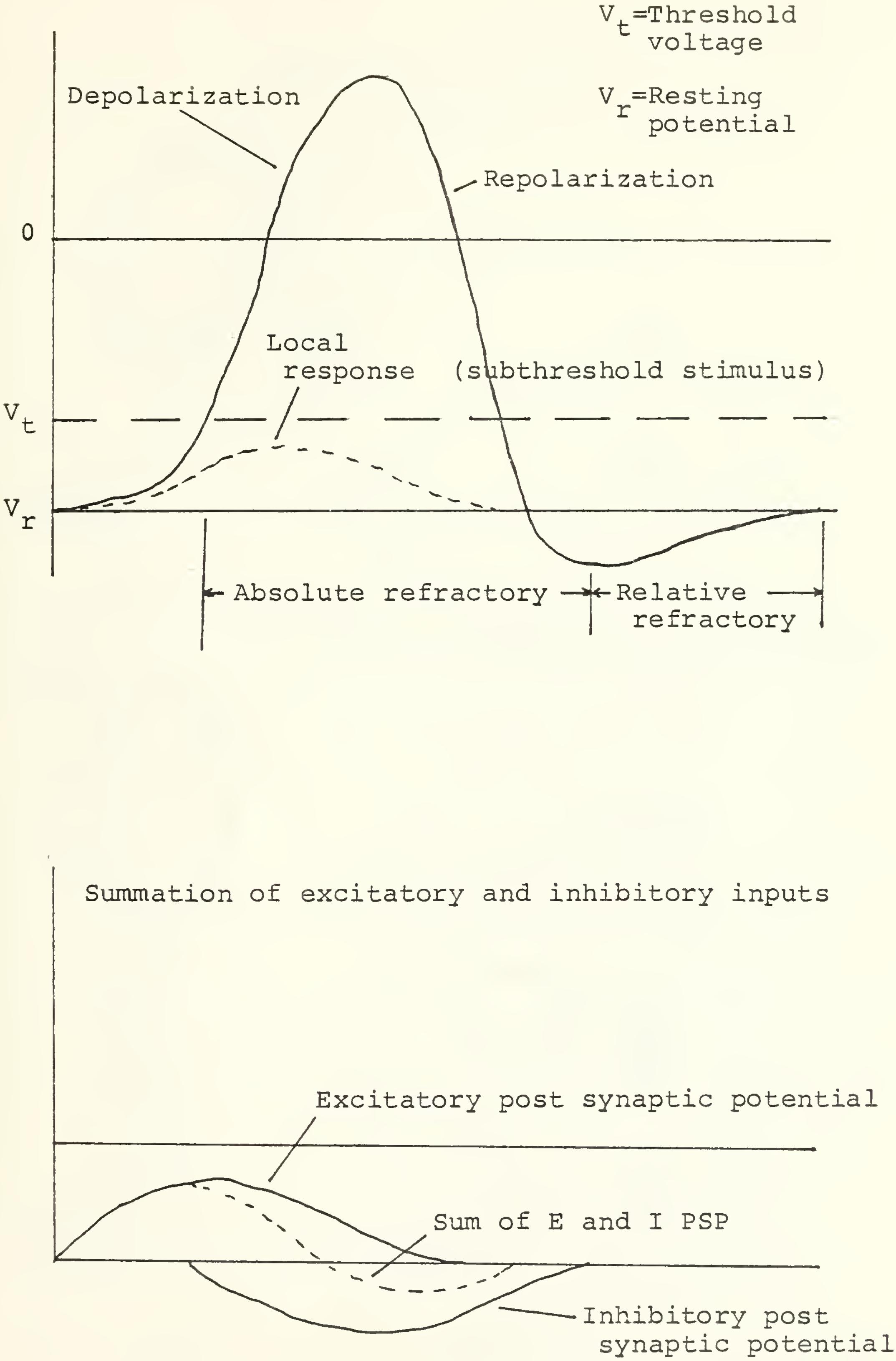


Figure 1. Post Synaptic Curves

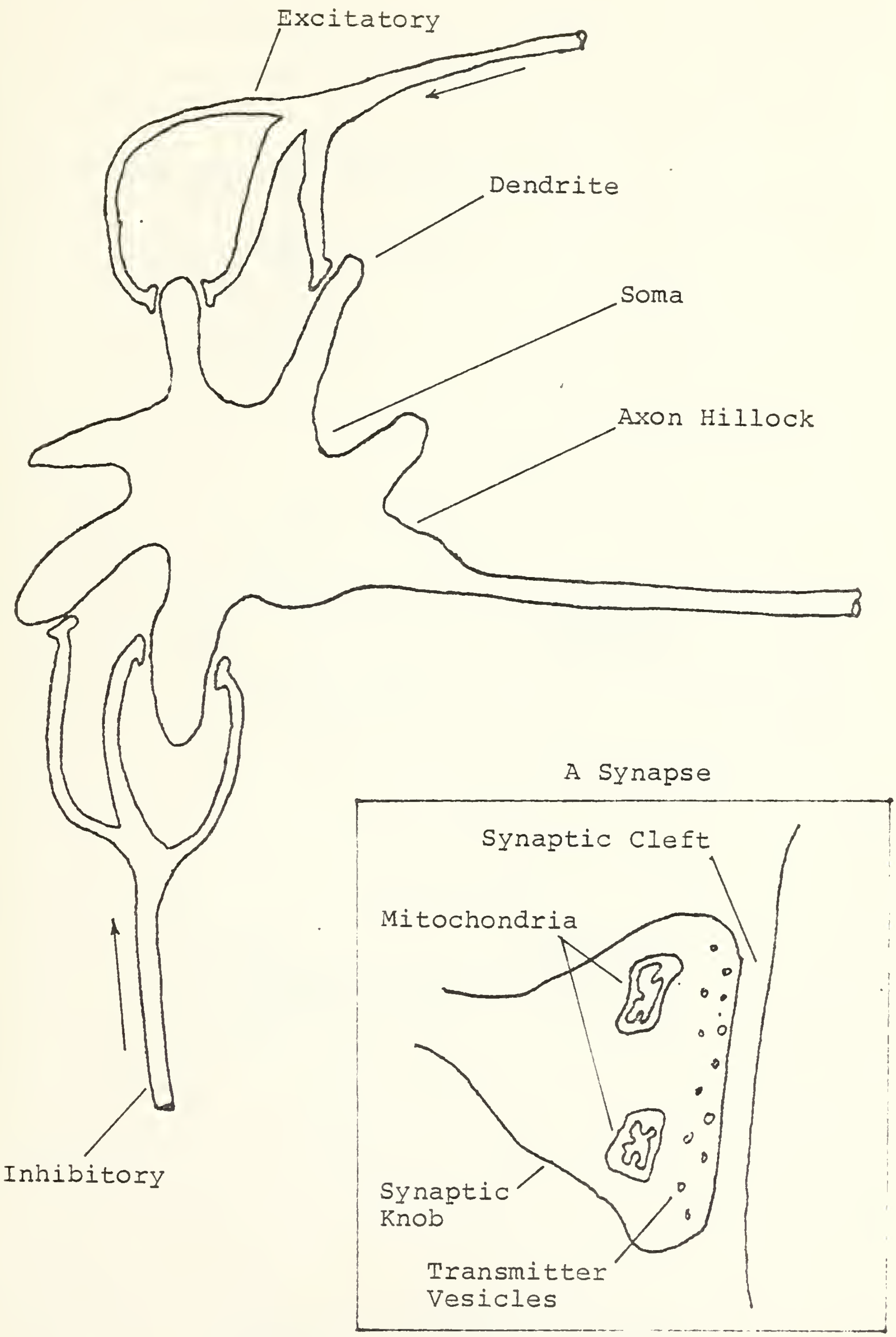


Figure 2. A Synapse

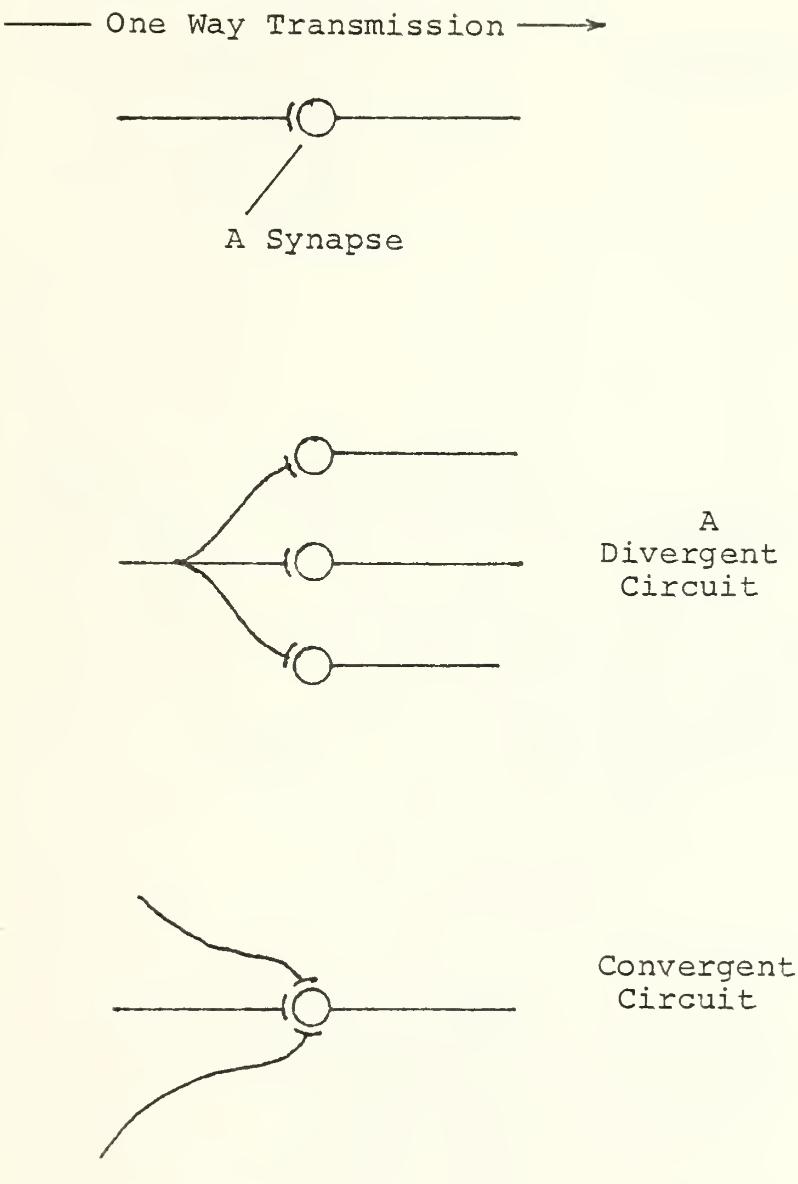
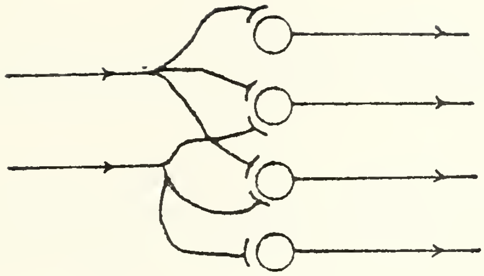
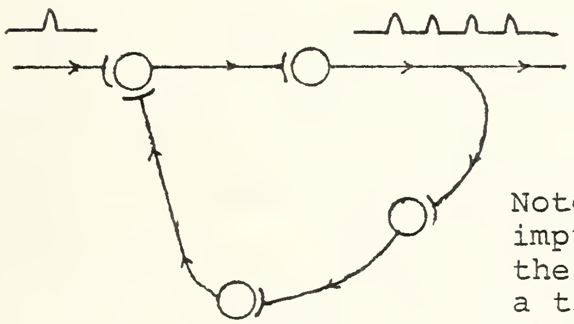


Figure 3. Synaptic Circuits

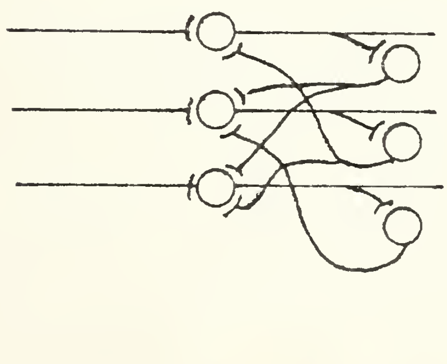


Congruent
Circuit



Reverberating
Circuit

Note that a single impulse coming in from the left could set up a train of pulses at the right.



Lateral
Inhibition
Circuit

Figure 4. Synaptic Circuits

III. PROCEDURES AND METHODS FOR OBTAINING AN EEG

A. LABORATORY EQUIPMENT UTILIZED

Beginning with the subject, a helmet which is a modified rock climber's hard hat is mounted on the head and provides a means of securing electrodes in fixed positions. The helmet has numbered holes cut in it, and on each hole is mounted a circular disk which can be rotated and which has four threaded holes for electrode insertion. The electrodes are made of specially machined and threaded plastic cylinders which house Beckman skin electrodes. Contact is completed between the encased skin electrode and scalp through a sponge-like material known as "Suca Blok", a Swedish trade name. This material is saturated with a 0.3 molar sodium-chloride solution, and application of electrode paste to the protruding tip ensures good electrode-scalp contact.

Electrical leads from the scalp electrodes are connected to an eight channel differential preamplifier where the EEG signal is amplified to a usable level. These preamplifiers are of superior quality. Amplification must be accomplished with minimum noise, minimum distortion and non-linear phase delay. Signals then proceed from the eight channel differential preamplifier to anti-aliasing filters. After filtering, the signals are approximately 10,000 times larger than when detected at the scalp electrodes. From these filters, the signals are fed into the analog conditioning element (ACE) where conversion from analog to digital is

performed, and it is here that callable program frequency band parameters are set in accordance with the Nyquist sampling criterion. Also, all channels are sampled simultaneously to avoid any artificial phase delay between channels.

Finally, data is fed into the Digital Electronic Corporation's PDP 11/40 computer which processes and stores information in real time, and has been most satisfactory as a central processor. It also controls two of the three available data display units.

The HP-141B four trace storage oscilloscope displays filtered analog data before sampling by the ACE, and gives early indication of excessive noise, equipment problems, and myograms. Processed digital data is displayed on a Tektronix storage oscilloscope controlled by the PDP 11/40. Both of these oscilloscopes are closely monitored during a run. The HP-7004B X-Y Recorder provides a smooth copy of research data and was used to plot all data figures presented herein.

B. APPLICABLE BRAIN GEOGRAPHY

Data presented is labelled according to the location of electrodes relative to the brain. The majority of data presented is recorded from the somatomotor area of the motor cortex which is located in the posterior part of the frontal lobe. Premotor is just forward of the motor area, and the most satisfactory electrode placement is called "Motor-Premotor".

Other electrode arrangements are called "Motor-Motor" and "Motor-Occipital". Motor-Motor refers to an electrode

arrangement of one on the left motor area and one on the right motor area. Motor-Occipital refers to one electrode on the left motor area and one on the left occipital lobe area.

C. PROGRAMS AND DATA

Two programs were utilized in EEG work- TWODET for real time signal processing and REPLAY for data analysis.

TWODET took signals from eight electrodes, averaged them, and subtracted this average from the two electrodes of interest, whose signals were included in the average. The remaining electrodes were placed around the two of interest, and subtraction of the average seemed to enhance the signals detected. The resultant two signals were then bandpass filtered and cross multiplied. TWODET stores on a disk the processed data from each of the two electrodes of interest, the cross multiplication trace, and the performance trace. The performance trace contained historical data on subject performance while engaged in a task (described later under stress tactics). Plots entitled "Correlation Plot" are produced by a program called REPLAY.VAR. This program computes a cycle by cycle integration of the cross multiplication trace displayed by TWODET. Results of this are plotted as a dot for each second of data. A complete disk of TWODET data contains 600 seconds of data which is subdivided into 100 second intervals. Thus, a correlation plot contains 600 dots and also the mean and standard deviation is computed and displayed for each 100 second segment or part as it will be termed hereinafter.

REPLAY is actually a series of programs which allow the viewer a variety of means of analysis and plotting data.

All of the TWODET plots presented in the data were plotted utilizing REPLAY.PLT, and as mentioned above, the correlation plots were obtained utilizing REPLAY.VAR.

In the data presentation, there is discussion of the "tegules". The ideal bandpass filtering necessary for isolating tegules of a certain frequency range is easily done after obtaining a DFT of the EEG. One simply sets all the complex spectral components which are not of interest to zero. Upon taking the inverse transform (IFT) one obtains a time domain record containing a sequence of tegules. It is to be understood that certain precautions are taken to avoid end effects and other possible distortions. Tegules can be observed on any of the TWODET data trace 1 or 3 plots contained herein. [Ref 1]

D. PREPARATIONS FOR AN EEG

Prior to obtaining an EEG, considerable attention was devoted to equipment, ensuring that it was energized, warmed up, and operating correctly. All possible checks were made prior to mounting electrodes on the subject, and necessary documentation was started. The program TWODET was called out, and a trial run was made to ensure that the program ran correctly and that monitoring equipment performed well. Team member assignments were made for control of the computer, peripheral equipment, and documentation of the run.

Great care was taken in properly mounting electrodes on the subject in the proper location and the arrangement was checked by another team member for accuracy. Finally, the subject was seated in the screened room and a trial run was made as a final check prior to starting the actual run. If

any electrode appeared noisy on the monitor scope, or if 60 Hz interference was observed, equipment and electrodes were checked again.

Working as a team, considerable efficiency was obtained, but if something did not work as it should have, all efforts on the EEG were stopped and maximal effort was applied to find the problem. Data was never recorded if anything was incorrect because such data would have been of no value to research.

E. MONITORING THE EEG

Even though preparations were extensive, monitoring the EEG in progress was considered to be of equal importance, and if anything malfunctioned, the run was aborted. Use of the two oscilloscopes described earlier made it a simple matter to observe progress, and in fact if a subject produced too many myograms, the data was discarded and the run was begun again. The care which went into gathering EEG data cannot be overly emphasized, and it was felt that data obtained was as pure as possible and free of artificialities.

F. DATA ANALYSIS

Every second of data was viewed and analyzed utilizing the series of REPLAY programs discussed earlier. Experience obtained through such analysis enhanced recognition of certain factors discussed later in the data presentation, and recognition of stress frames became quite simple.

In the data presentation, there is a discussion of Correlation plots and TWODET data plots. The correlation plots were considered pertinent because they indicated the departure of the mean from a zero reference. The TWODET data plots each display one second of data as discussed earlier, and it was here that the majority of time in analysis was spent. Performance is also discussed and some performance data is presented in units of time. These times were obtained by measuring all frames in a given run and determining the average time required for the subject to perform the task, which is described later.

IV. STRESS DEFINITION AND DISCUSSION

A. GENERAL

Dictionary definitions of stress, frustration, fatigue, and tension distinguish one from the other, but a common result of these conditions is a degradation of performance whether physical or mental. For purposes of this paper, stress is defined in the broadest sense, encompassing all the terms above. Any time a trained operator is unable to perform a skilled motor task, whatever the reason, it is considered to be due to stress, excluding obvious physical ailments.

B. SOME CONSIDERATIONS

Physiologically, there are a massive number of aspects to consider when attempting to discuss stress. Endocrinology, and specifically the function of the adrenal medullae and associated secretion of epinephrine and norepinephrine are pertinent considerations. The effects of these hormones on neurotransmitters are discussed in Ref 2, but the physiological effects of other hormones are more directly related to stress and are discussed below.

C. THE ADRENAL CORTEX

The adrenal glands lie at the superior poles of the two kidneys and are composed of the adrenal medulla and the adrenal cortex. The adrenal cortex secretes an entirely different group of hormones from those secreted by the medulla and these are called corticosteroids. Corticosteroids are further classified into two major types called mineralocorticoids and glucocorticoids. Glucocorticoids are particularly important in helping a person resist different types of stress. Most glucocorticoid activity of the adrenocortical secretions results from the secretion of cortisol with a small amount provided by corticosterone and cortisone. Cortisol in turn effects the metabolism of carbohydrates, proteins, and fats.

The best known metabolic effect of cortisol is its ability to stimulate gluconeogenesis by the liver as much as ten fold. As a result of this increased gluconeogenesis, there is an increase of glycogen in liver cells but concentration in other cells of the body is not increased and may in fact even be decreased. Glucose utilization by the cells is also slightly decreased which may be a result of enhanced utilization of fats, as discussed below. Blood glucose concentration therefore rises and this is called adrenal diabetes.

Cortisol reduces protein stores in all body cells except those of the liver and gastrointestinal tract. This is caused by a decreased rate of protein anabolism and an increased rate of protein catabolism. The mechanism which causes this is completely unknown, however. Another exception to protein depletion is the plasma protein

concentration. Cortisol is capable of enhancing both amino acid transport into liver cells and liver enzymes required for protein anabolism, and this is believed to be the reason for the prctein concentration exceptions mentioned above. Since there is an increased catalysis of cellular proteins, there is an increase in blood amino acid concentration, which might play a valuable role in providing an available supply of amino acids in time of need.

Similar to the amino acid mobilization from extrahepatic cells by cortisol, there is a mobilization of fatty acids from adipose tissue which in turn increases concentration of unesterified fatty acids in plasma, and increases their utilization for energy. Thus, cortisol shifts the metabolic systems of cells from utilization of glucose to utilization of fatty acids for energy.

Secretion of corticotropin or ACTH by the adenohypophysis (anterior pituitary gland) stimulates the release of cortisol, corticosterone, and certain other hormones by the adrenal cortex. Although corticotropin is continually secreted by the adenohypophysis, the secretion can be increased as much as twentyfold by physiological stress. As the level of cortisol concentration in the blood rises, it causes negative feedback to the adenohypophysis which in turn reduces secretion of corticotropin. This feedback system is not completely understood, but cortisol may have an effect which is the feedback stimulus rather than acting directly on the adenohypophysis. Almost any type of stress causes an immediate increase in corticotropin secretion which is rapidly followed by increased adrenocortical secretion of cortisol. The significant benefit of this process is not clear, but a theory offered in Ref 3 is that the glucocorticoids cause rapid mobilization of fats and amino acids from cellular stores and makes them available for synthesis of other compounds

needed by different tissues of the body.

The reason for the above discussion of hormonal effects is that modification of their levels are taken as a definite and objective physiological sign that the individual is undergoing stress. It is also recognized that if the individual is able to respond with appropriate changes of the adrenal cortex hormonal levels, he is better able to resist during a stressful situation, although his resistance may take several days to build up. On the other hand the release of norepinephrine and epinephrine is a short term event but usually also helps the individual to combat stress.

V. STRESS DETECTION THEORY

A. GENERAL

In some people, the presence of stress and the impact which it may have on a demanding task such as controlling aircraft is not easily discerned until a major calamity has occurred. It is the author's opinion that the both the mechanisms and technology are present to quantitatively define and detect stress. through the EEG, observation of brain activity and response signatures as discussed in Ref 4 is made possible. Further, modification of these signatures or patterns should be just as easy to identify at this point, and in the future it should be quite an easy task to detect the presence of stress, and also the degree of stress experienced. For those personnel daily engaged in activities which require both tremendous motor coordination skill and continuous decision-making, a pattern peculiar to that individual could be made to be utilized as a basis for detection of stress. From that time onward, thresholds could be set which, if exceeded, would be an exact indication of stress too great to permit the associated responsibility.

B. SPECIFICS

In the data presented, four factors are discussed which provide an insight to detection of stress. The first is activity of the cerebral cortex as sampled by electrodes placed on the individual's head. The second is observation of the cross-multiplication of these two electrode traces, and the resulting patterns. Third, performance of a simple task is observed and recorded along with the electrode activity samples. Fourth, correlation of recorded data is shown to also be an indication of a stressful situation.

Time required to place electrodes and record and observe data in a non-research environment could easily be confined to a period of only a very few minutes-probably close to fifteen or so for an experienced group. The potential savings in loss of equipment and lives would more than offset cost of such a system, and both military and industry should reap tremendous benefits.

VI. STRESS TACTICS

A. GENERAL

The Bio Team has designed a tasking system which is utilized in the conduct of EEG's. References 5 and 6 describe the system in detail and only a brief outline is given here.

While seated in a screened room, the subject concentrated on a dot displayed on a CRO which was randomly displaced. The subject attempted to maintain the dot in a centered position using a control stick mounted on his right side. Frequency of the random disturbances was set by a potentiometer in the clock circuit, and this frequency was termed "clock-rate". The clock controlled the rate of operation of a bank of shift registers. Also contained in the tasking circuitry were 5 Hz and 7 Hz sine wave oscillators. When a certain combination of shift register outputs occurred, the outputs of the oscillators were simultaneously sampled, and the dot was displaced in the X (roll) and Y (pitch) directions accordingly. Thus, both the occurrence of dot displacement and the amount of displacement appeared to be random. The control stick served as a single control over roll and pitch and configuration was such that any person could easily learn the task in a very few minutes. Thus, in order to create a stress situation, the task was made more challenging by increased clock rates, control reversal, and application of electric shock.

B. CLOCK RATE

The simplest tactic to employ is a change in clock rate which results in a change in frequency of pip displacements. Clock rate is adjustable from 0.8 to 21 Hz, but only the range from 0.8 to approximately 3.0 Hz is within the realm of reason for subjects. Above 3.0 Hz, subjects had a tendency to ignore tasking altogether. The two frequencies most commonly employed were 1.5 Hz and 2.8 Hz.

C. CONTROL REVERSAL

Insertion of a double-pole, double-throw switch in the roll and pitch output circuits made it an easy matter to confuse a subject otherwise secure in his control of the task. Effectively, the CRO was rotated ninety degrees clockwise, but the subject had to realize and compensate for this instantaneous change which took place at predetermined intervals during a run.

D. ELECTRIC SHOCK

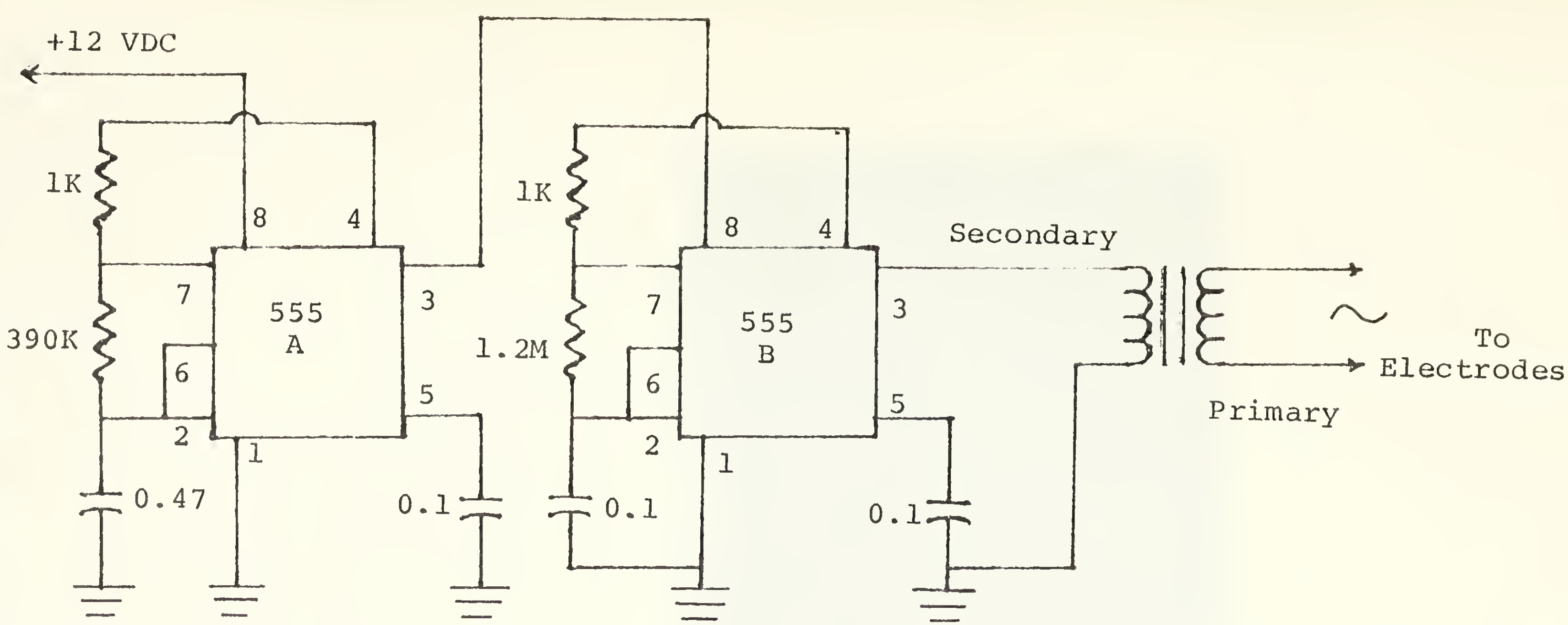
Electric shock proved to be the most effective and most difficult tactic in inducing stress. When properly applied, it was found that no subject ever completely acclimated to it, and interviews with subjects convinced the author that it was a most effective means of inducing stress.

A simple arrangement of two cascaded "555" timing chips

and associated RC networks was utilized. A twelve volt dry cell provided the input voltage, and an inexpensive audio transformer was employed as a step-up device, although the original intention was only that it be an isolation device. Referring to Fig 5, chip A drives chip B at a 4 Hz rate. Chip B has a 30 Hz output of nearly 12 volts into the transformer secondary winding. Output of the transformer (Fig 6) is a distorted square wave which measures 20 volts peak-to-peak.

Two Beckman skin electrodes were mounted on a piece of plexiglas, and tape secured the arrangement to the subject. Most commonly, these electrodes were placed on the subject's left upper arm in a spot which, when energized, caused twitches of the biceps.

Primary difficulty with this arrangement was a tendency to pick up stray 60 Hz signals and an associated sensitivity to electrode-skin resistance. Both problems were overcome.



Output 3 of 555 A is a 30 Hz signal of 12 volts peak to peak. The output from 555 B pin 3 was a modified 30 Hz signal chopped at a 4 Hz rate.

Figure 5. Electric Shock Circuit

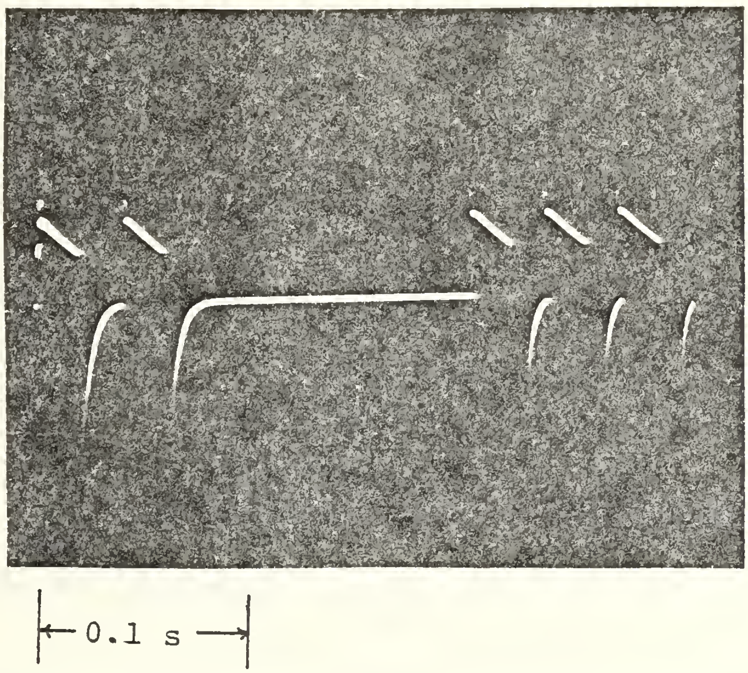


Figure 6. Electric Shock Circuit Output Waveform

VII. DATA PRESENTATION

A. FIRST MOTOR-PREMOTOR RUN

1. General

The motor-premotor electrode arrangement has been shown to be the best for measuring cortex activity at the preferred frequency of 70-95 Hz while engaged in a task, as discussed in Ref 6. For this reason, it was hoped that stress would be equally detectable in the same frequency band, at the same location.

2. Correlation Plot

Figure 7 shows correlation for a non-stress run and Fig 8 shows correlation for a stress run. Scenarios were otherwise identical for each run so that comparison of the two was simplified. Note that correlation for the stress run was significantly higher than for the run without stress.

3. TWODET Data

Up to this point, the subject had been exposed to a random combination of clock rates, stick reversals, and electric shock of various length periods. Electric shock

intervals were chosen on a purely arbitrary basis and little thought was given to task relation. As a result, the subject seemingly became nearly acclimated to electric shock, at least to the point that it no longer interfered with his performance, and Fig 9 shows typical results. Later runs presented display traces of greater magnitude, and as a result it was decided that the subject was not truly stressed in this run.

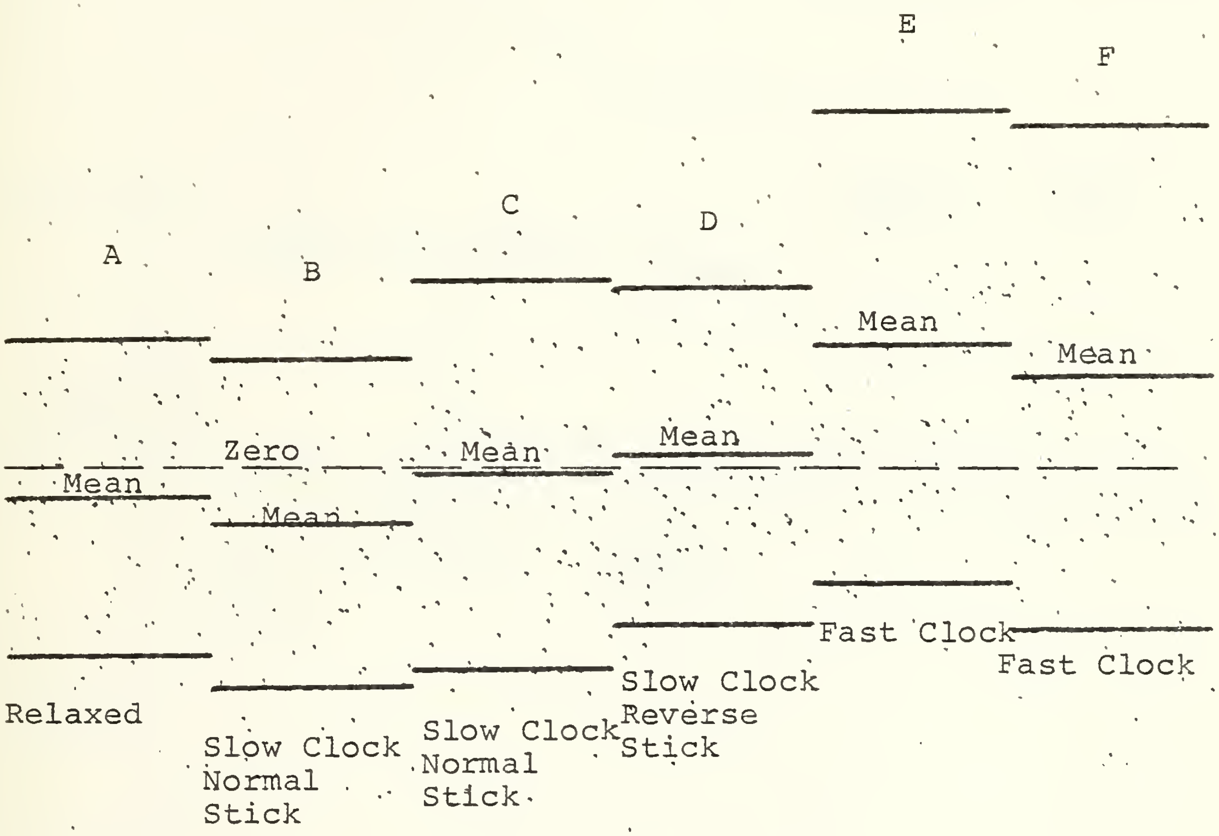


Figure 7. Motor-Premotor No Stress Correlation

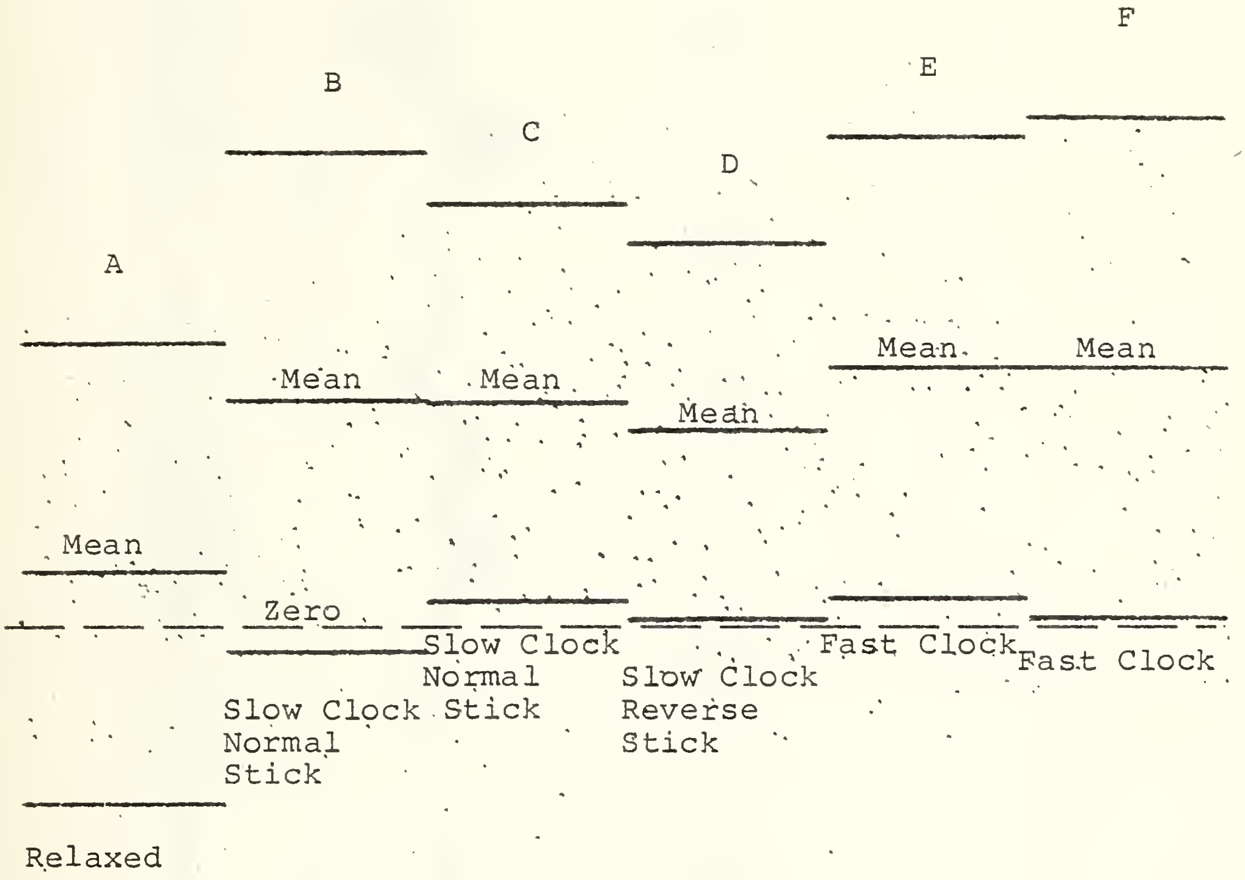


Figure 8. Motor-Premotor Stress Correlation Plot

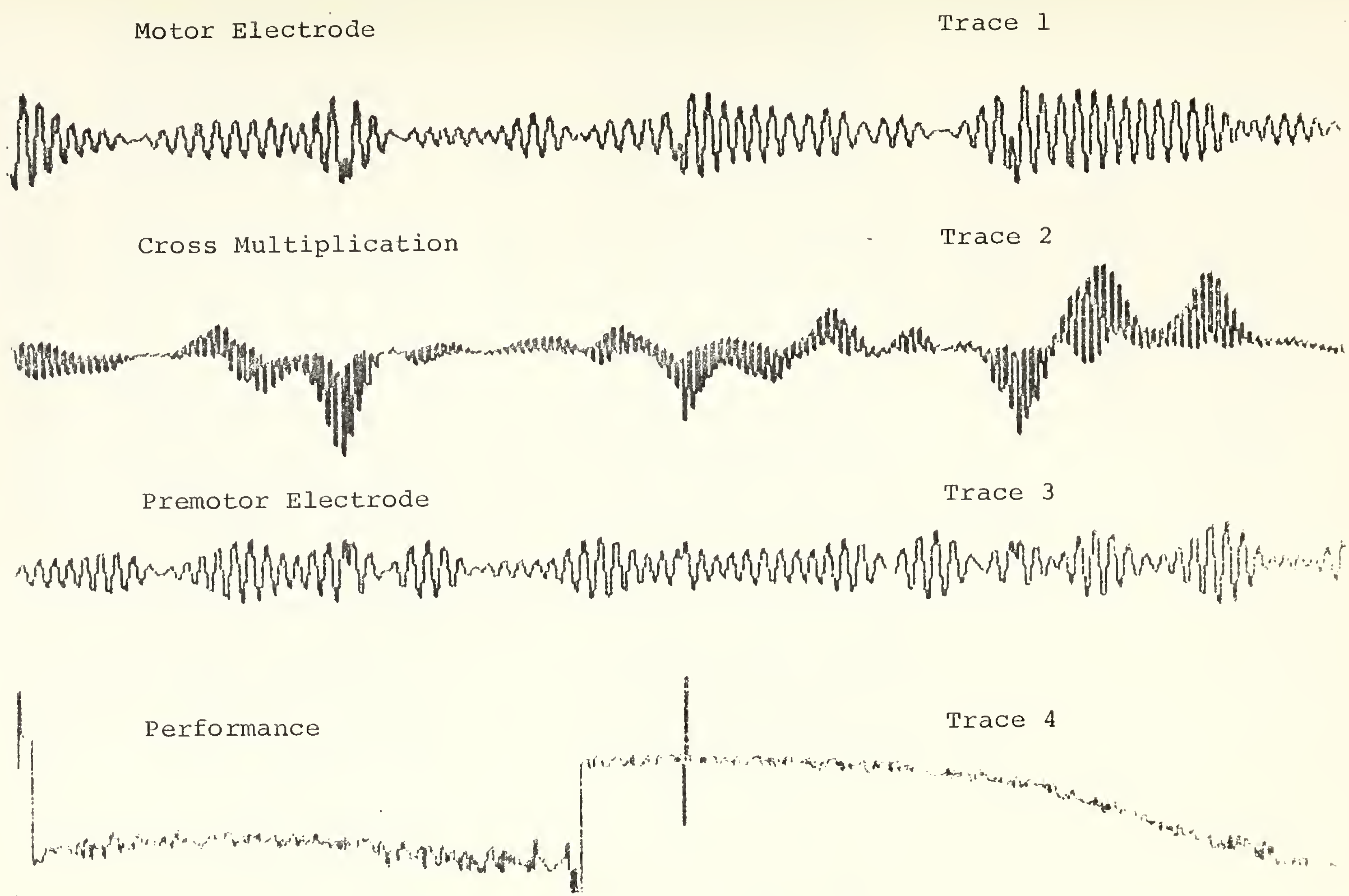


Figure 9. Motor-premotor Stress Plot

B. SECOND MOTOR-PREMOTOR RUN

1. Correlation Plot

a. A Change In Stress Tactics

At this time it was decided to record both stress and non-stress data on a single disk in order to eliminate as many variables as possible. Also, a new method for applying electric shock was employed. Simply stated, each time the dot was displaced, the subject received a shock of approximately 250 milliseconds duration. Pip displacements are noted by a marker as annotated on Fig 11. Clock rate was maintained at a constant rate.

b. Results

Results of the changes cited above were dramatic. Figure 10 clearly shows marked differences between runs. Note that all stress runs were greater than one standard deviation above the zero line. This data was recorded with the same subject as all previous data presented, and this was considered a departure point upon which a realistic comparison could be made with other subjects in stress detection.

2. Non-Stress TWODET Data

As a basis for comparison with following plots, Fig

11 shows a very typical non-stress plot. The smooth well-defined performance trace is an early indication of good non-stressful reaction. Tegule size and the maximum peaks recorded on trace 2 should be kept in mind when viewing the stress plots which follow.

3. Stress TWODET Data

a. Discussion

Figures 12 through 17 are of data recorded during stress application, and each depicts poor performance, significant tegules, and large positive peaks on trace 2. Note that in some figures, the subject displaced the dot so far from center that trace 4 saturated.

b. Performance

As anticipated, performance was degraded by stress. In order to ensure that true results were recorded, performance times with stress are indicated first for all frames, then for only the frames in which the subject had normal stick control (all non-stress parts were with normal stick control).

1. No Stress 0.43 s
2. Stress 0.66 s, Normal Stick 0.72 s
3. No Stress 0.45 s
4. Stress 0.62 s, Normal Stick 0.63 s
5. No Stress 0.46 s
6. Stress 0.61 s, Normal Stick 0.56 s

As in any learning process, the decreasing trend in performance times (indicating improved performance) suggests a possible acclimation to stress tactics as was experienced earlier.

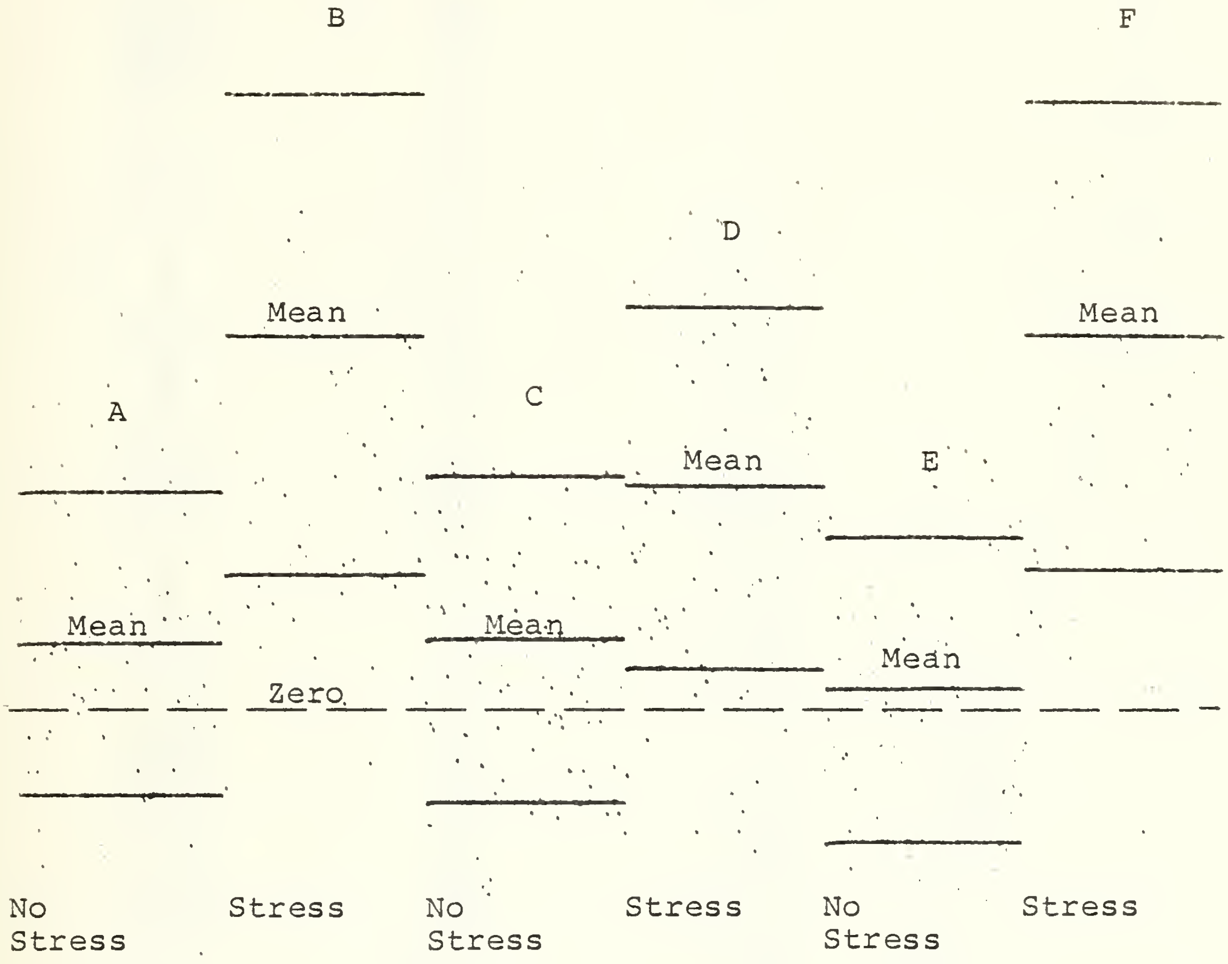


Figure 10. Motor-premotor Correlation

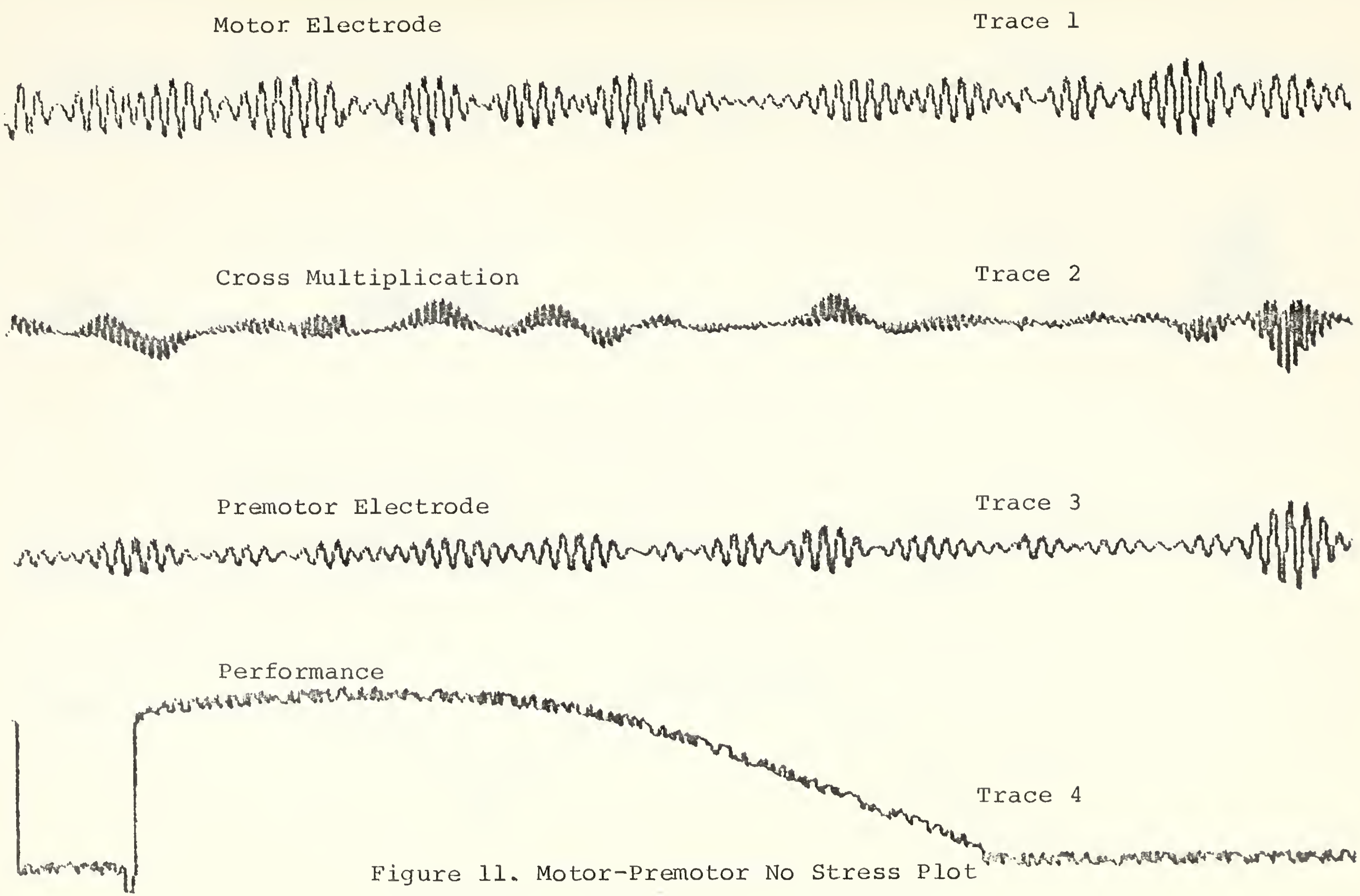


Figure 11. Motor-Premotor No Stress Plot

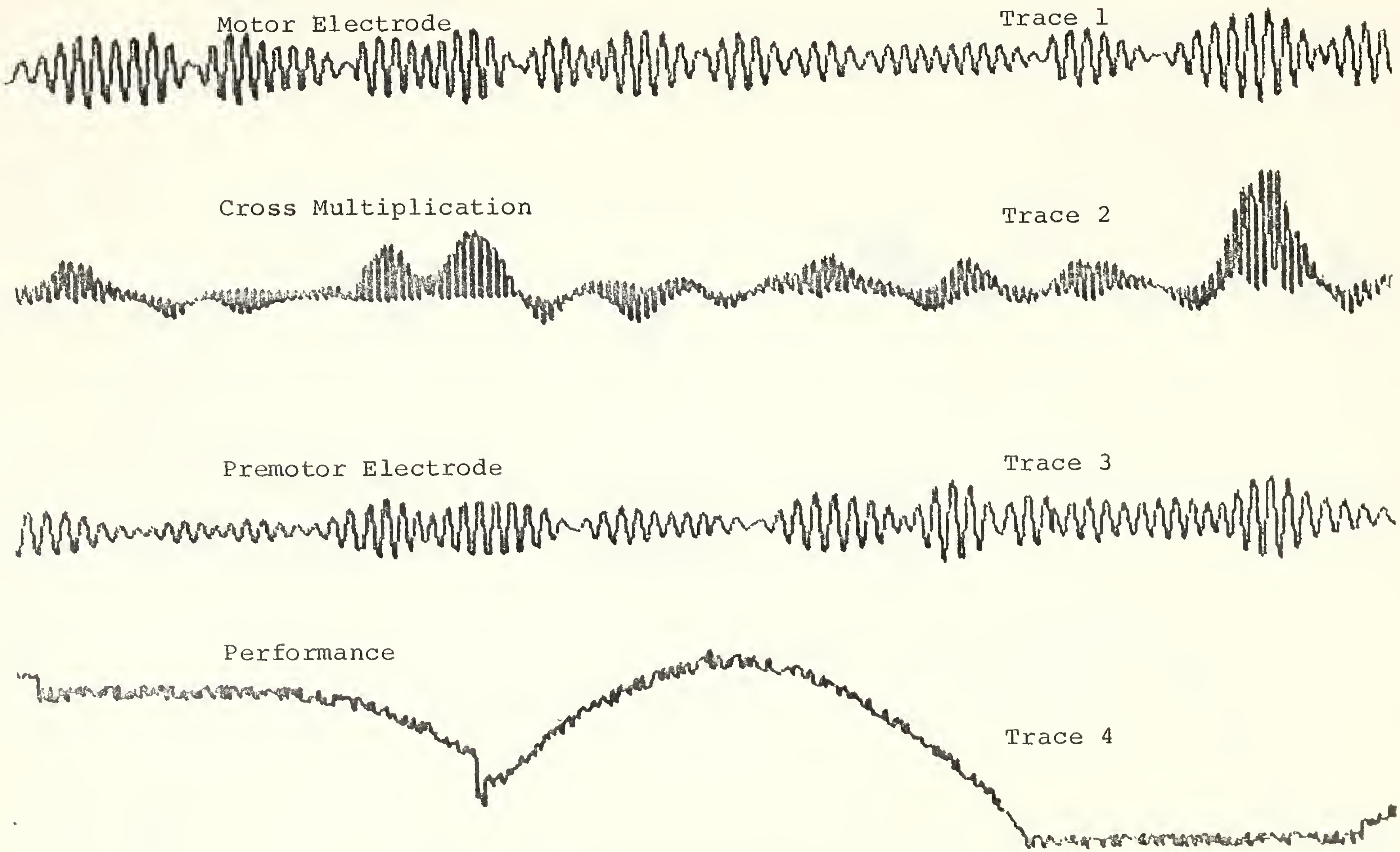


Figure 12. Motor-premotor Stress Plot

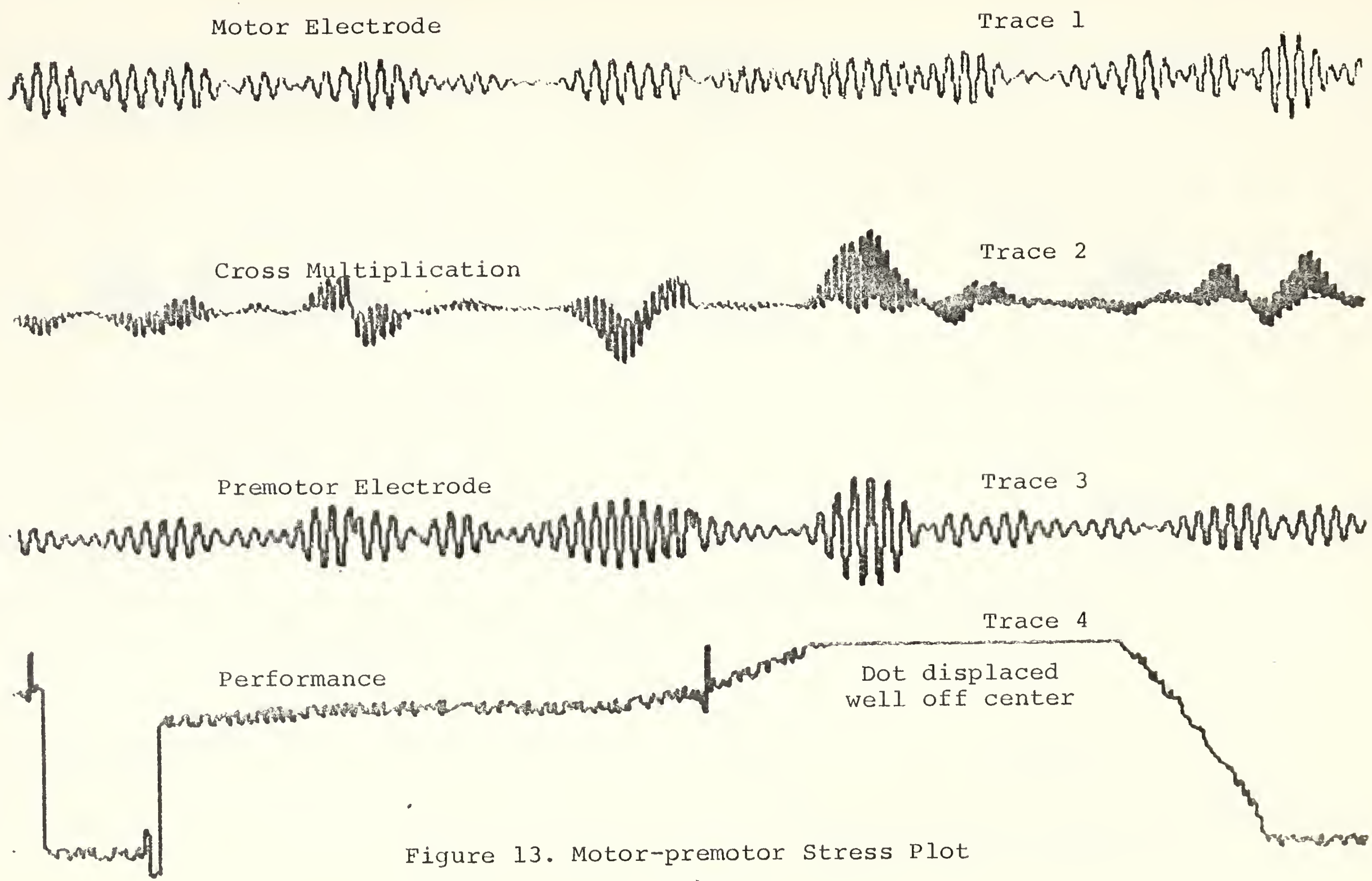


Figure 13. Motor-premotor Stress Plot

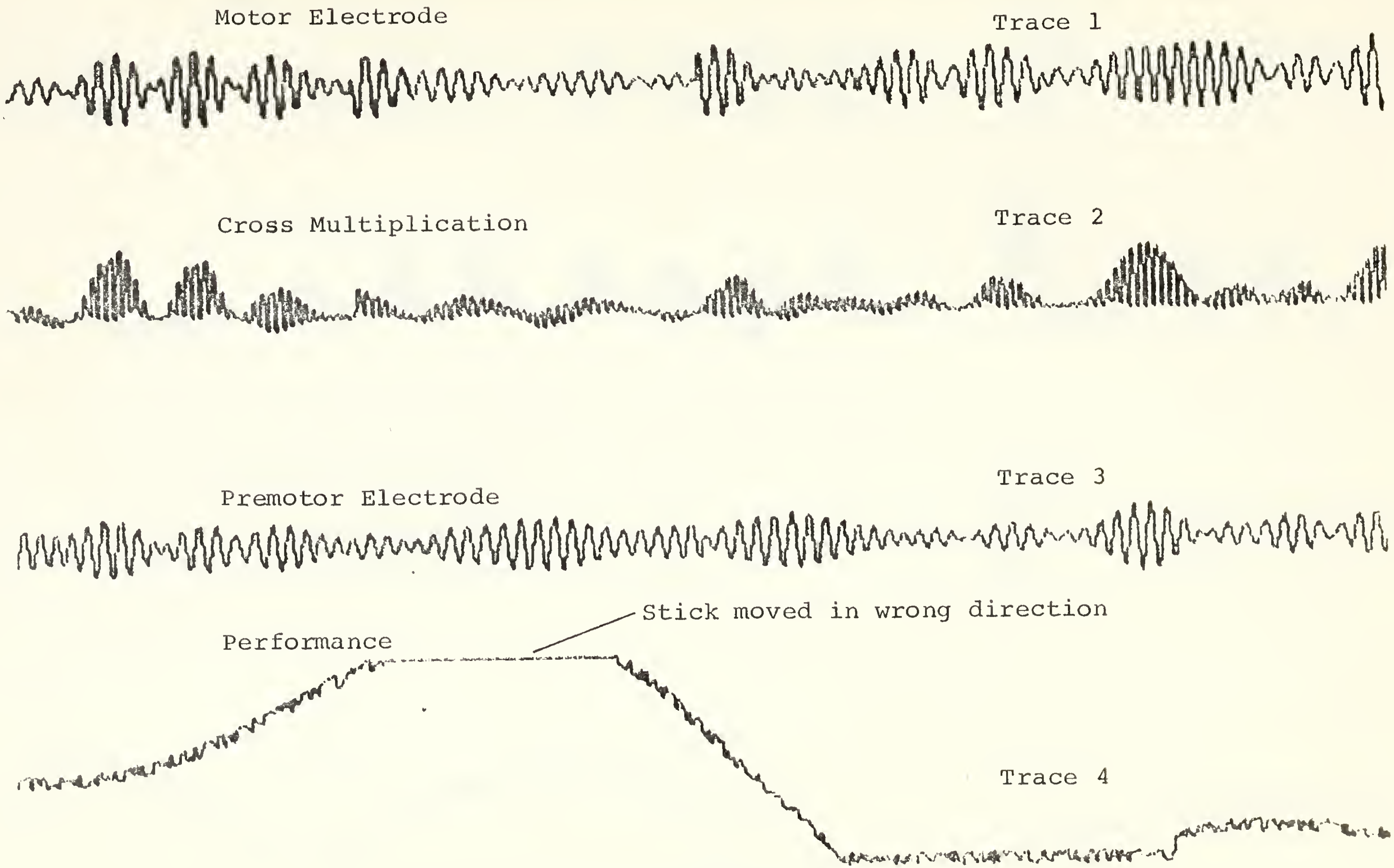


Figure 14. Motor-Premotor Stress Plot

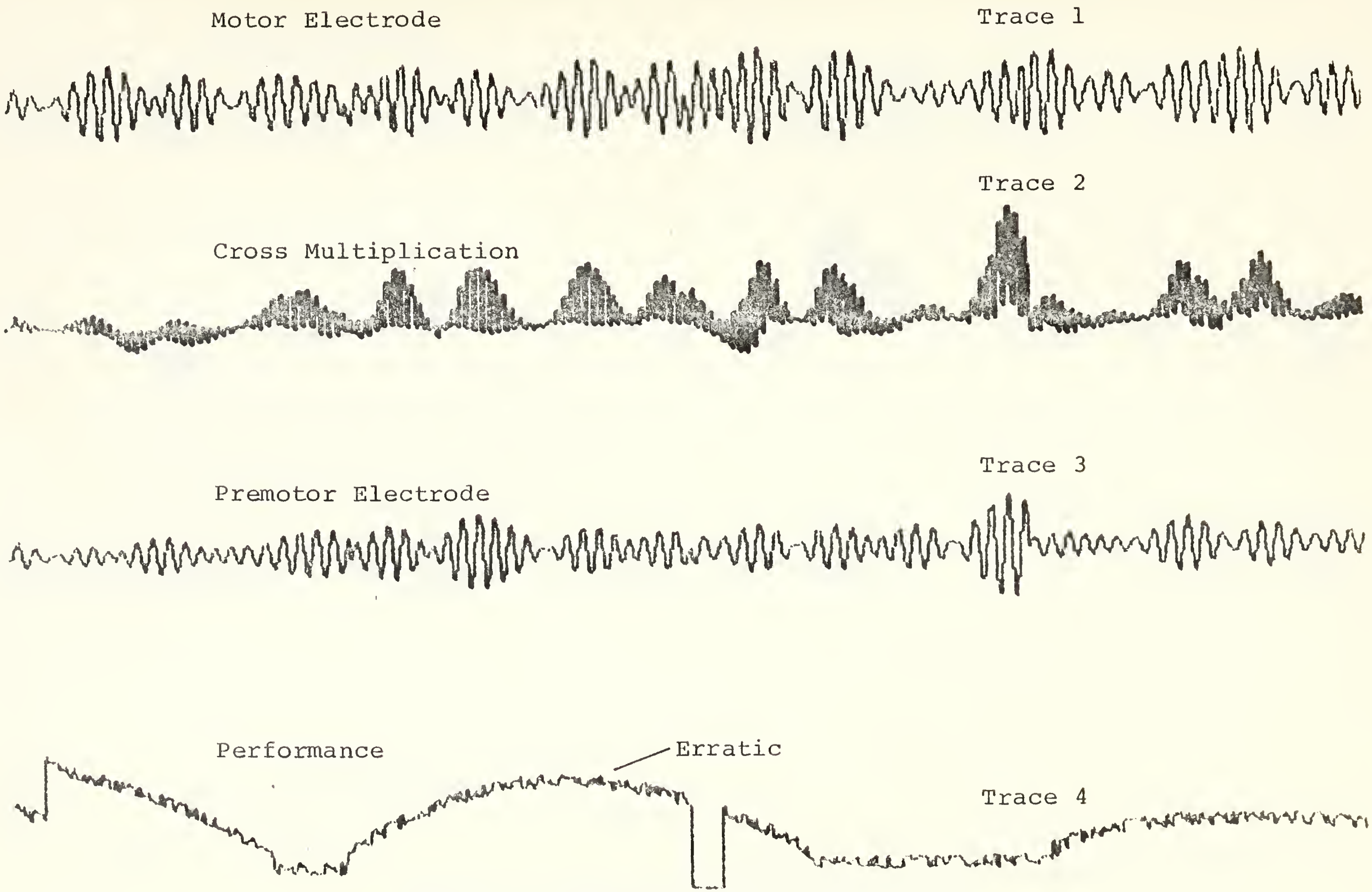


Figure 15. Motor-Premotor Stress Plot

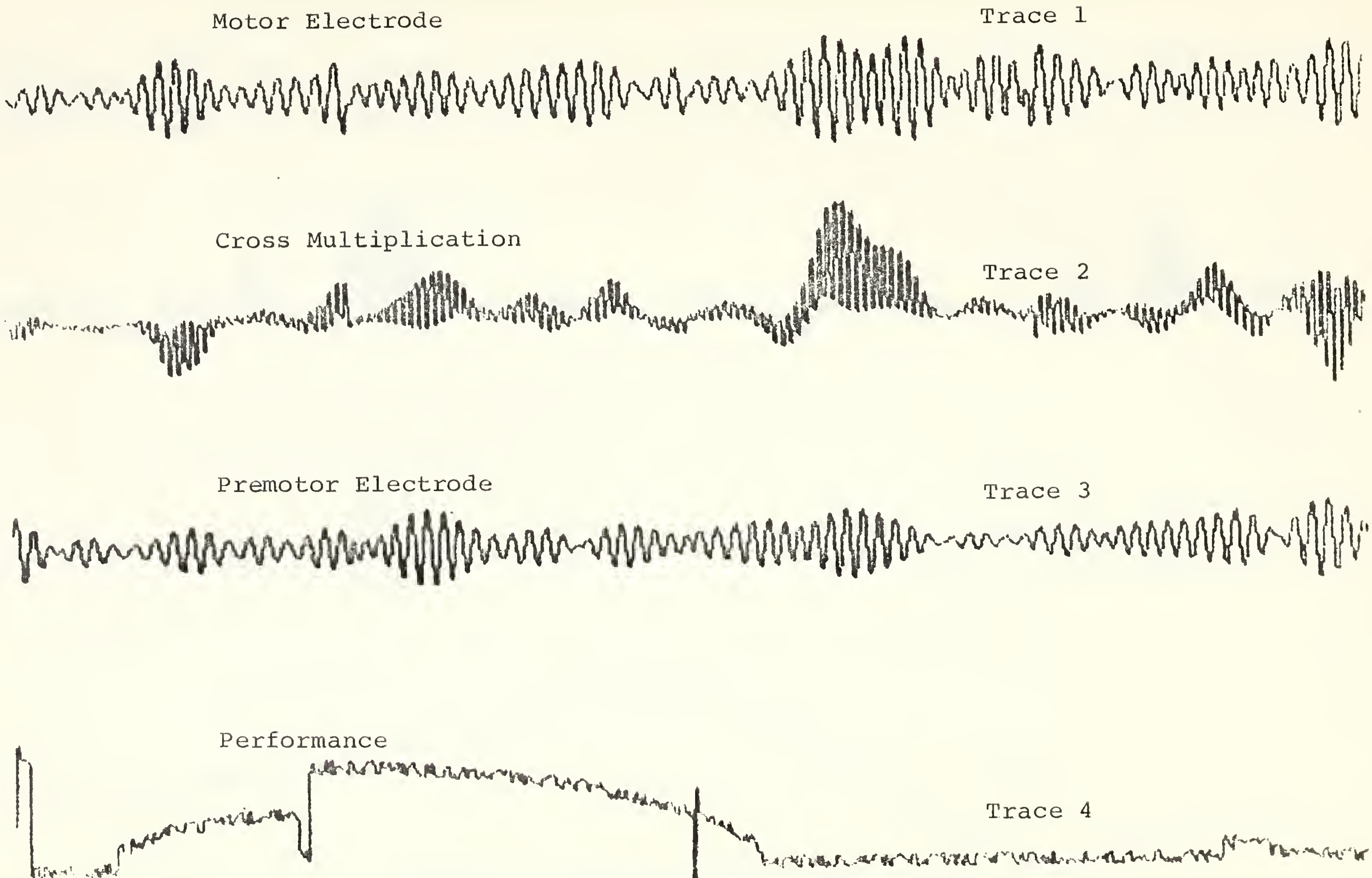


Figure 16. Motor-Premotor Stress Plot

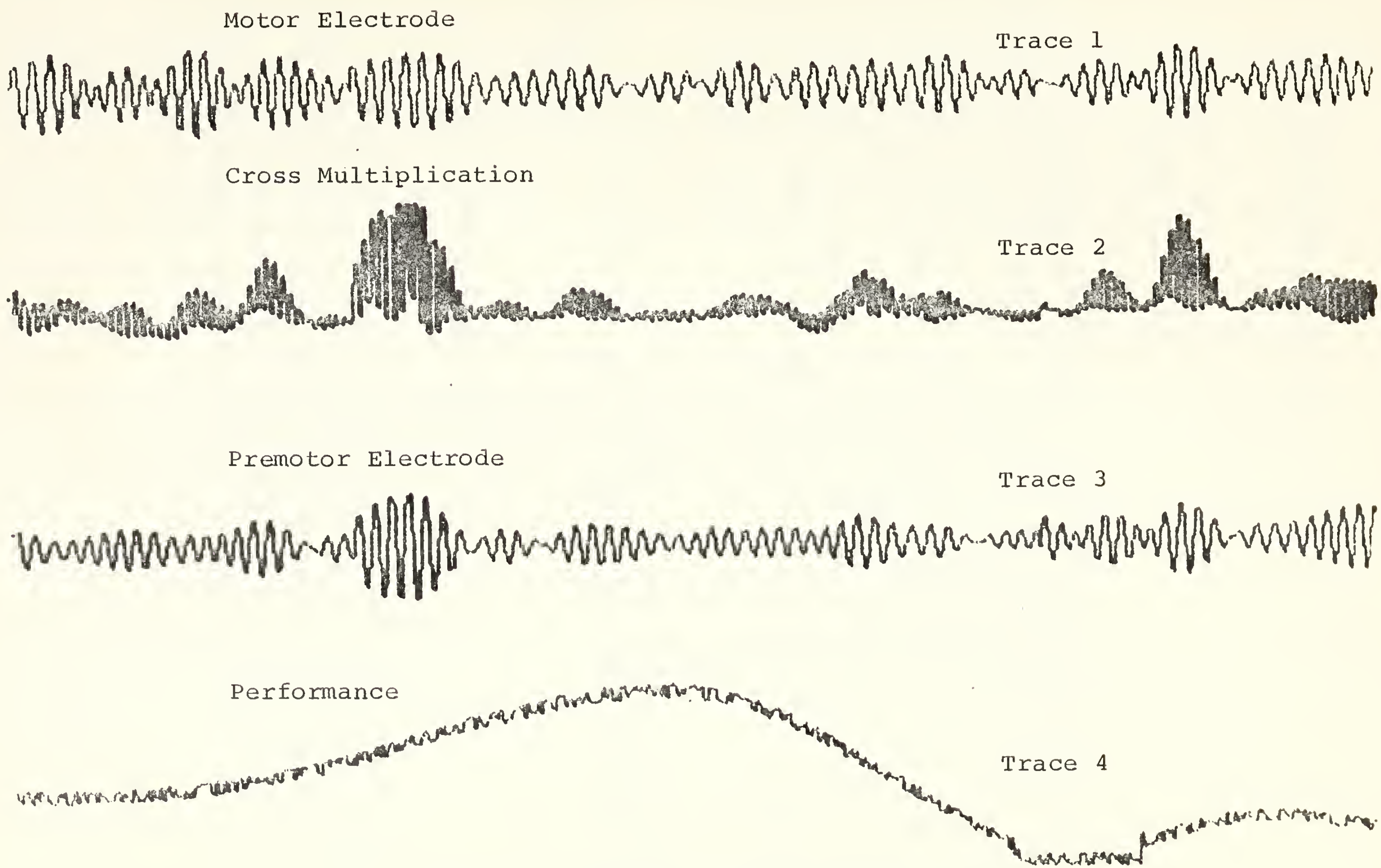


Figure 17. Motor-Premotor Stress Plot

C. THIRD MOTOR-PREMOTOR RUN

1. Correlation Plot

A different subject was utilized for this run and results of the correlation (Fig 18) were as expected in the first two parts. The subject stated that he only felt stressed in the first stress part and that the electric shock did not distract him in parts D and F. The means for these two parts would be consistent with his comments. Performance data which is presented later indicated that the subject was more distracted than in the other two stress parts. As in the last run presented, all data was recorded on a single disk.

Note that the no stress parts display increasing means while the stress parts display decreasing means of correlation.

2. Non-Stress TWODET Data

Figures 19 and 20 display typical non-stress plots while actively centering the dot and while simply holding the dot in one position, respectively. Tegule size and trace 2 cross-multiplication size are quite normal for runs with no stress applied and are useful for comparison with subsequent stress data.

3. Stress TWODET Data

a. Discussion

Figures 21, 22, and 23 are of data recorded during stress application and each shows significantly larger tegules and saturation on trace 2. Figure 22 is annotated on trace 4 where a dot displacement by the subject is seen. Such displacements were observed frequently and may be an indication of an unsteady hand due to stress.

b. Performance

Even though the subject stated he felt no stress in the second two parts, performance indicates otherwise. Again, all non-stress parts were with normal stick. Also, for the stress parts, two figures are again presented-an average of all frames and then an average for only those frames with normal stick control.

1. No Stress 0.54 s
2. Stress 1.93 s, Normal Stick 0.82 s
3. No Stress 0.62 s
4. Stress 1.03 s, Normal Stick 0.94 s
5. No Stress 0.59 s
6. Stress 1.55 s, Normal Stick 1.40 s

Note that of the stress parts, the subject's performance was better in the part he stated was truly stressful. The second two stress parts, when he felt no

stress, indicated significantly poorer performance when only the normal stick times were considered. It is interesting to speculate that the subject was not aware of being stressed and thought his performance to be unaffected.

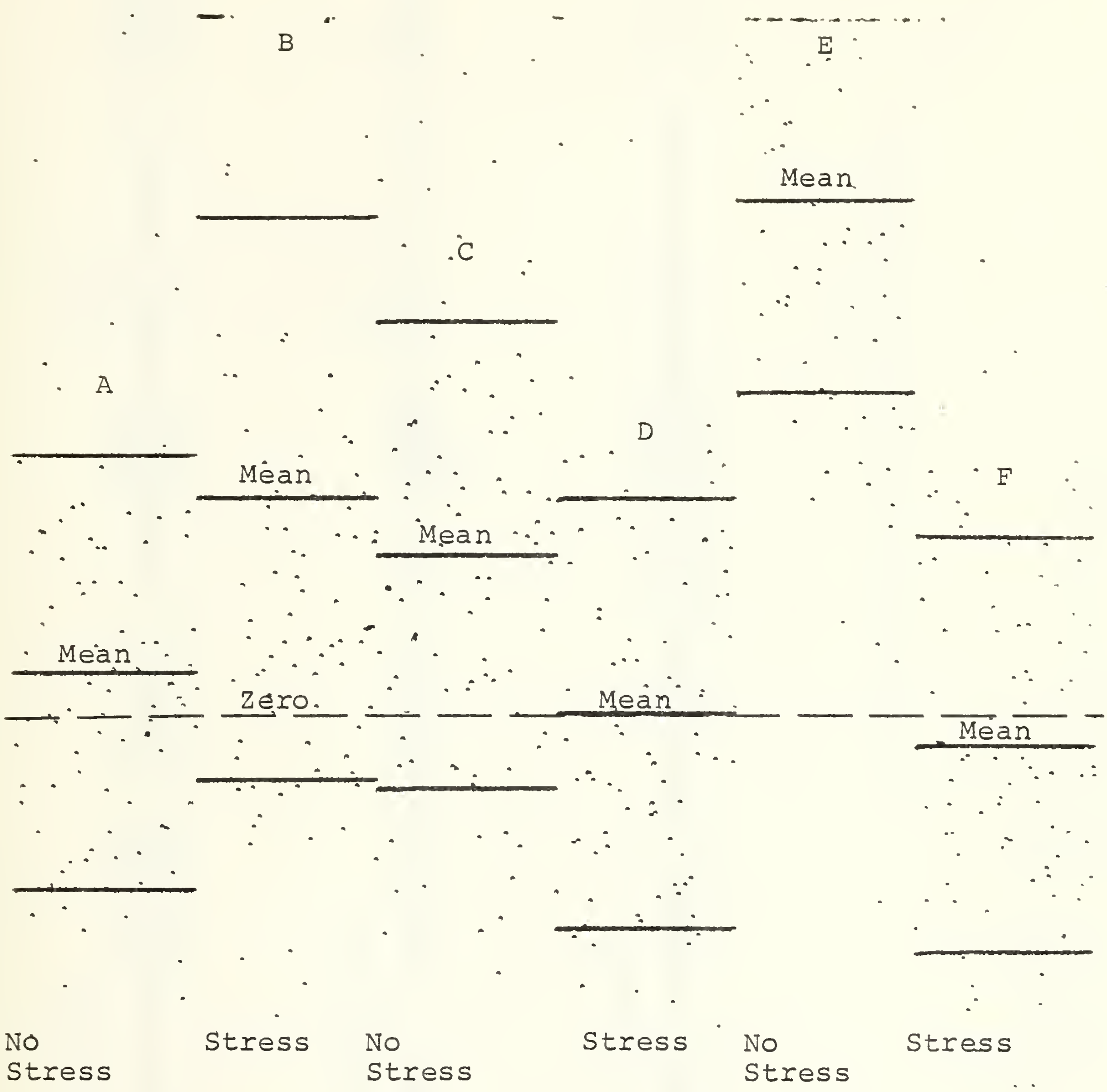


Figure 18. Motor-Premotor Correlation Plot

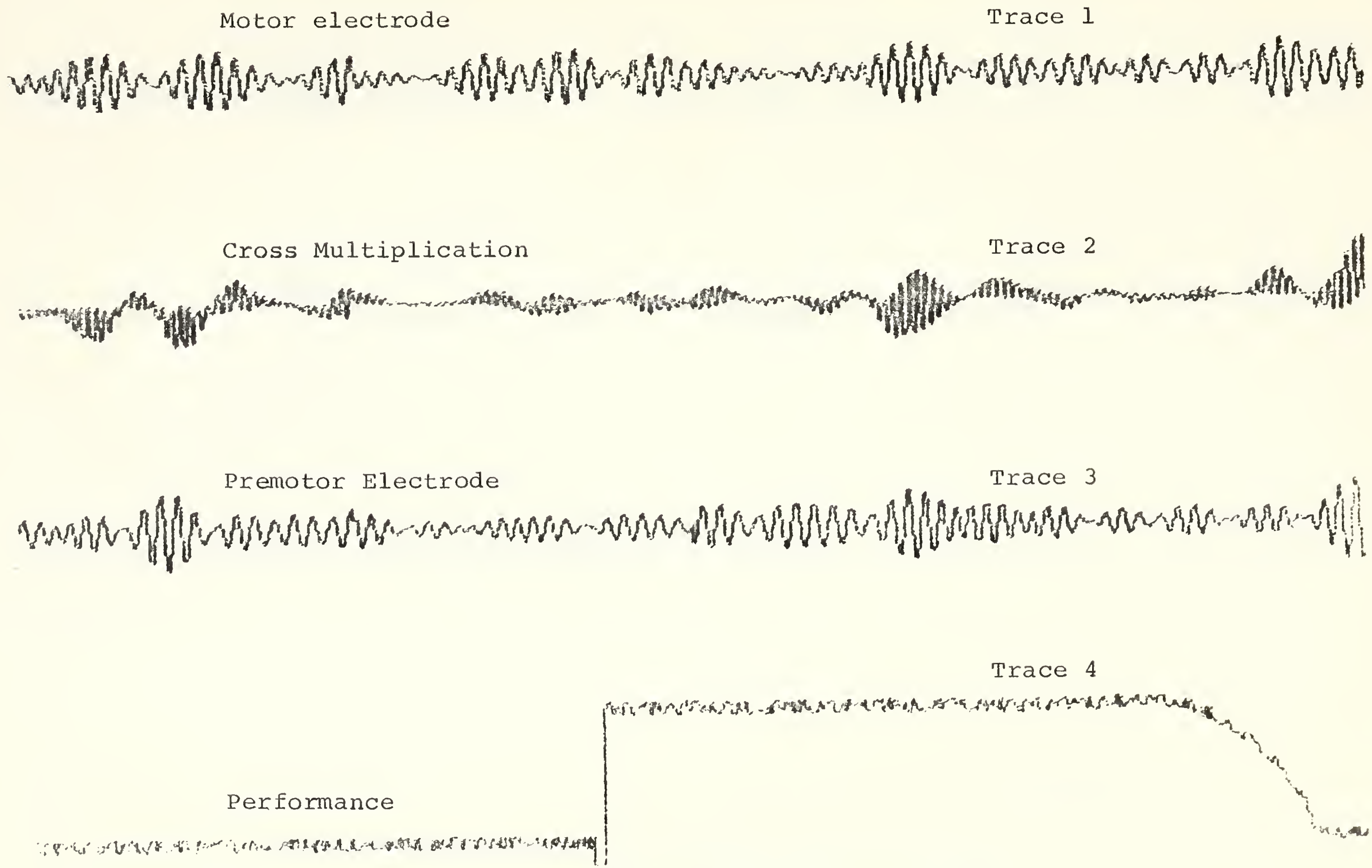


Figure 19. Motor-Premotor No Stress Plot

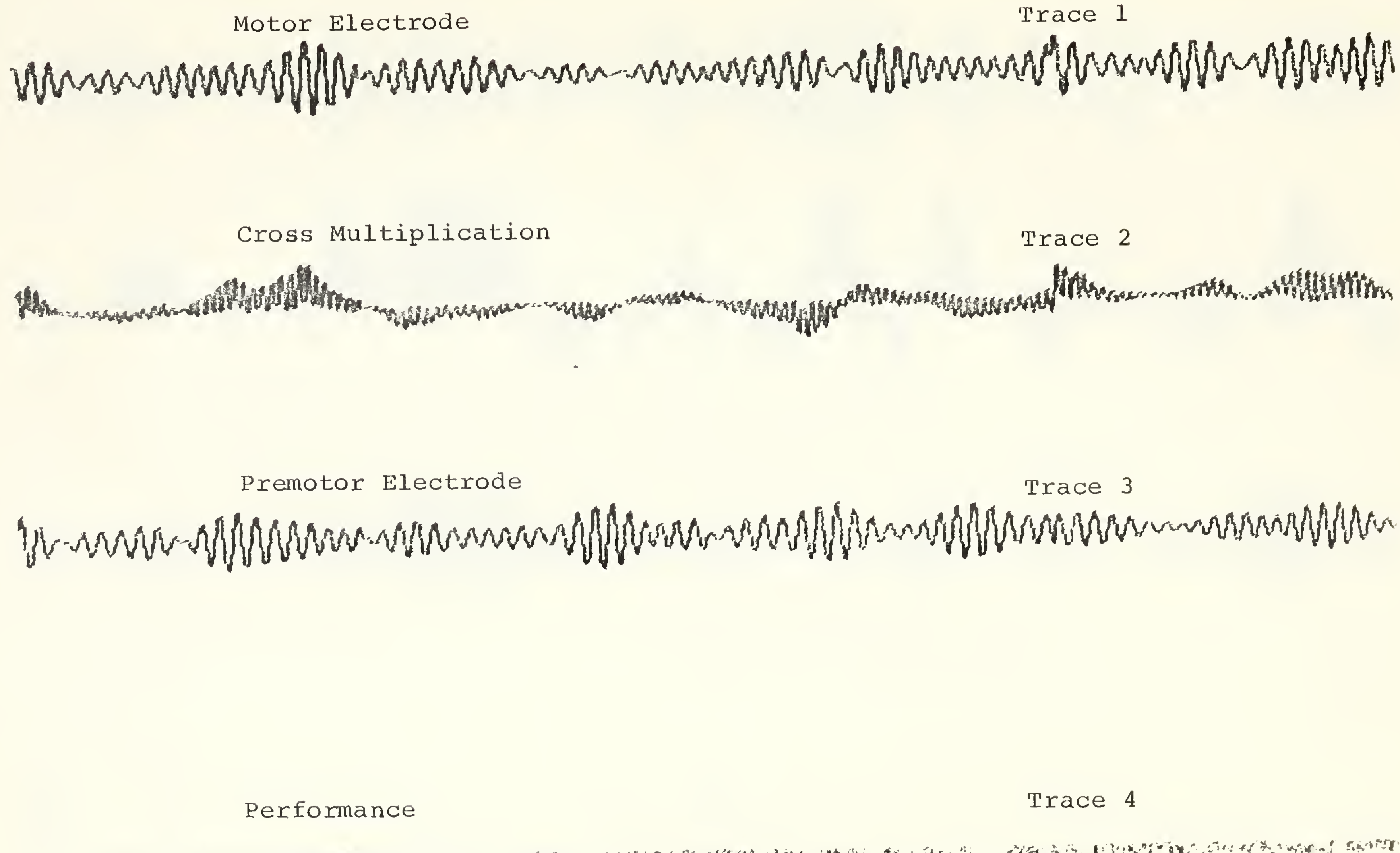


Figure 20. Motor-Premotor No Stress Plot

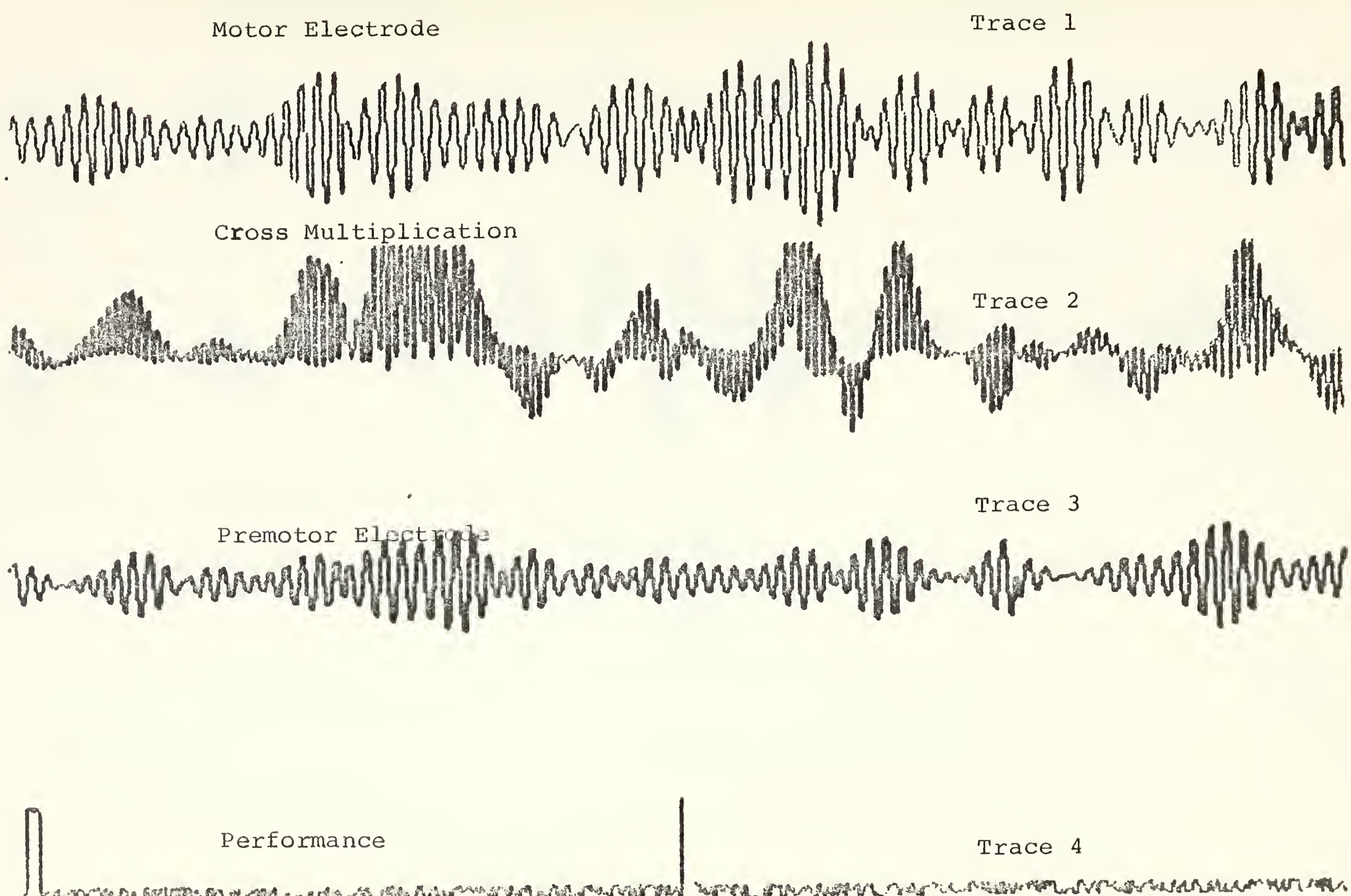


Figure 21. Motor-Premotor Stress Plot

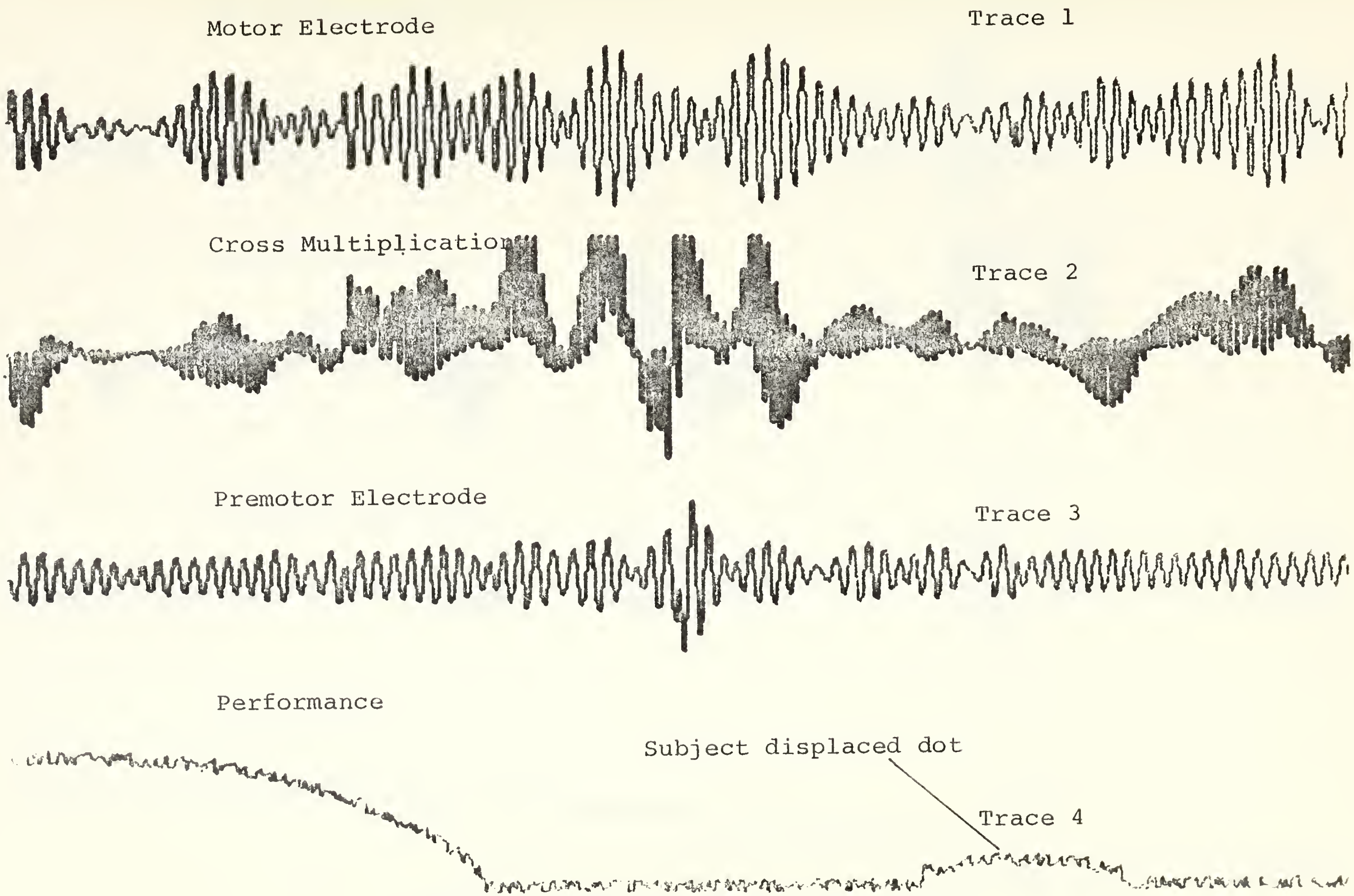


Figure 22. Motor-Premotor Stress Plot

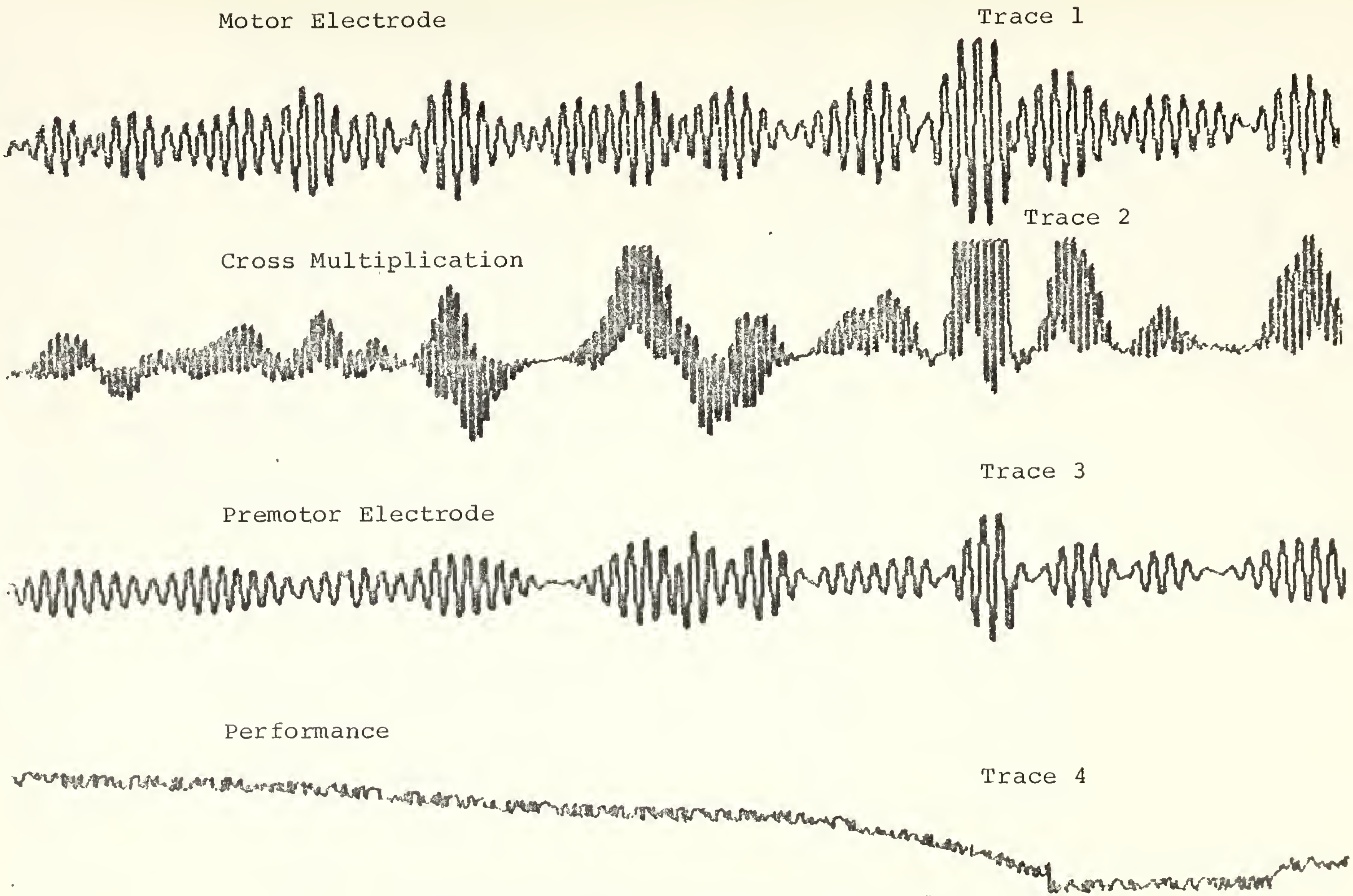


Figure 23. Motor-Premotor Stress Plot

D. MOTOR-OCCIPITAL RUN

1. General

An earlier run was made with electrodes placed on the left motor and left occipital areas of the brain to determine whether stress could be detected with this electrode arrangement.

As in the first motor-premotor run, two runs were actually recorded- one without stress and one with stress. Scenarios were otherwise identical for each run.

2. Correlation Plot

Figures 24 and 25 are the no stress and stress correlation plots respectively. Note the lower means in the stress run which is opposite to results obtained with the motor-premotor electrode arrangement. The largest separation of means occurred in parts D of the two types of run, and was possibly due to a greater requirement to concentrate with reverse stick. The parts in which the subject was tasked by a fast clock were not significantly different which may indicate that the fast clock required more work but no more concentration than a slow clock rate.

3. Non-Stress TWODET Data

Figure 26 is a typical plot recorded when the subject was simply holding the dot in a centered position

and Fig 27 is typical of data recorded when the subject was actively engaged in centering the dot. Tegules and cross multiplication peaks are considerably smaller than those displayed in the stress plots which follow. Also note that performance was accurate with no uncertainty or wavering displayed.

4. Stress TWODET Data

Figures 28 through 31 were recorded during the stress run, and tegules are significantly larger. The cross multiplication traces show saturation in places indicating that large tegules were either in phase or nearly 180 degrees out of phase, but the tegules were not saturated.

5. Performance

Reference 4 showed average performance times for an identical run with no stress. These are listed below along with the stress run average times required to zero the dot after displacement. In every case, performance was degraded by the inducement of stress. One other important point noticed here was the effect of Biofeedback (BFB) which reduced run-to-run stress times when present.

1. Normal Stick, BFB: No Stress 0.49 s, Stress 0.62 s
2. Normal Stick, No BFB: No Stress 0.48 s, Stress 0.74 s
3. Reverse Stick, BFB: No Stress 0.75 s, Stress 0.87 s
4. Fast Clock, BFB, Normal Stick: No Stress 0.50 s, Stress 0.62 s
5. Fast Clock, No BFB, Normal Stick: No Stress 0.47 s, Stress 0.69 s

The No Stress times listed were an average of several runs. Individual data from a single run of approximately the same time frame agreed with times listed with one exception. The reverse stick No Stress time was 0.95 s. This was longer than the stress time recorded. Note that in Fig 31, the subject perhaps ceased to care about his performance.

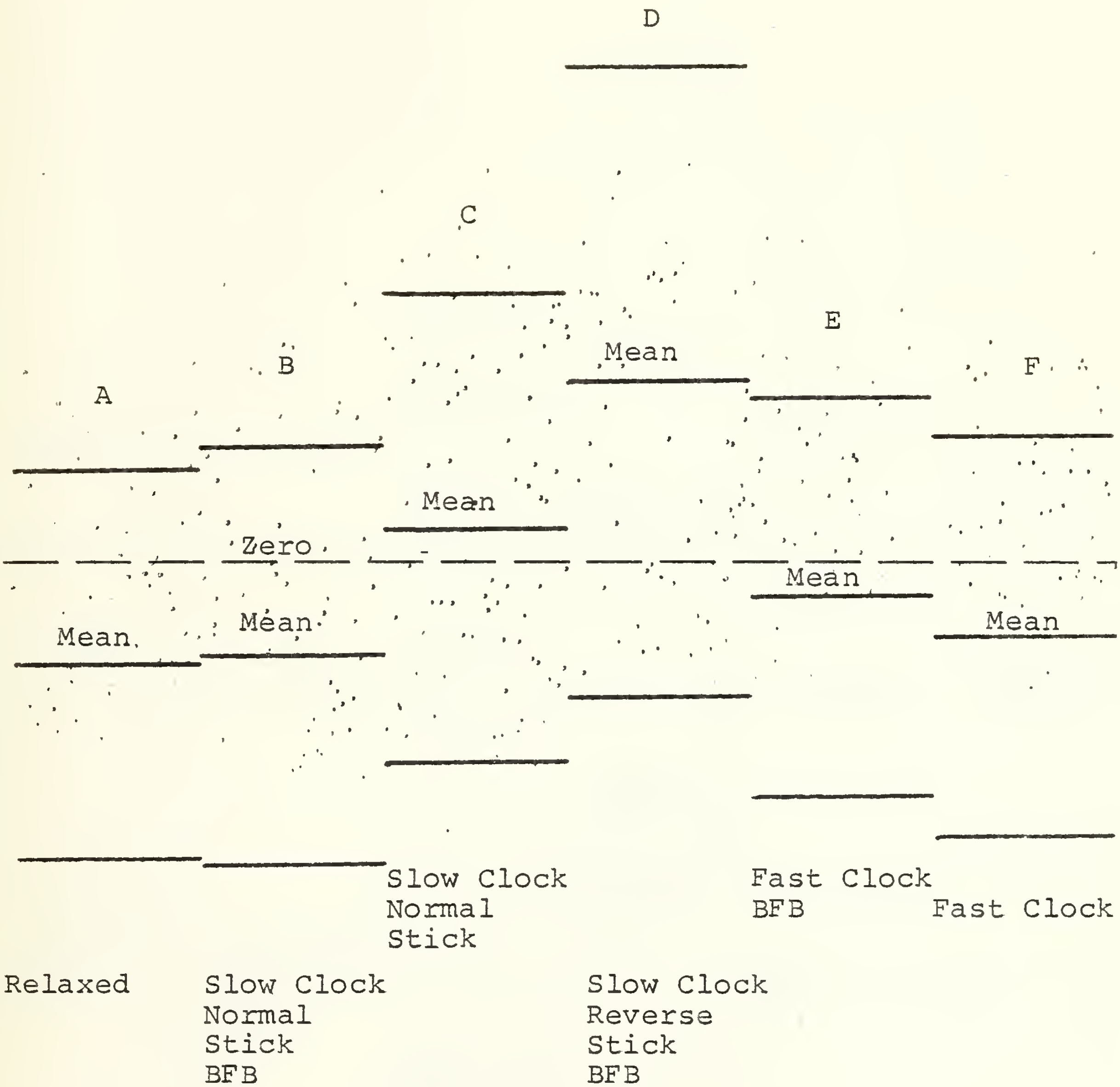


Figure 24. No Stress Correlation Plot

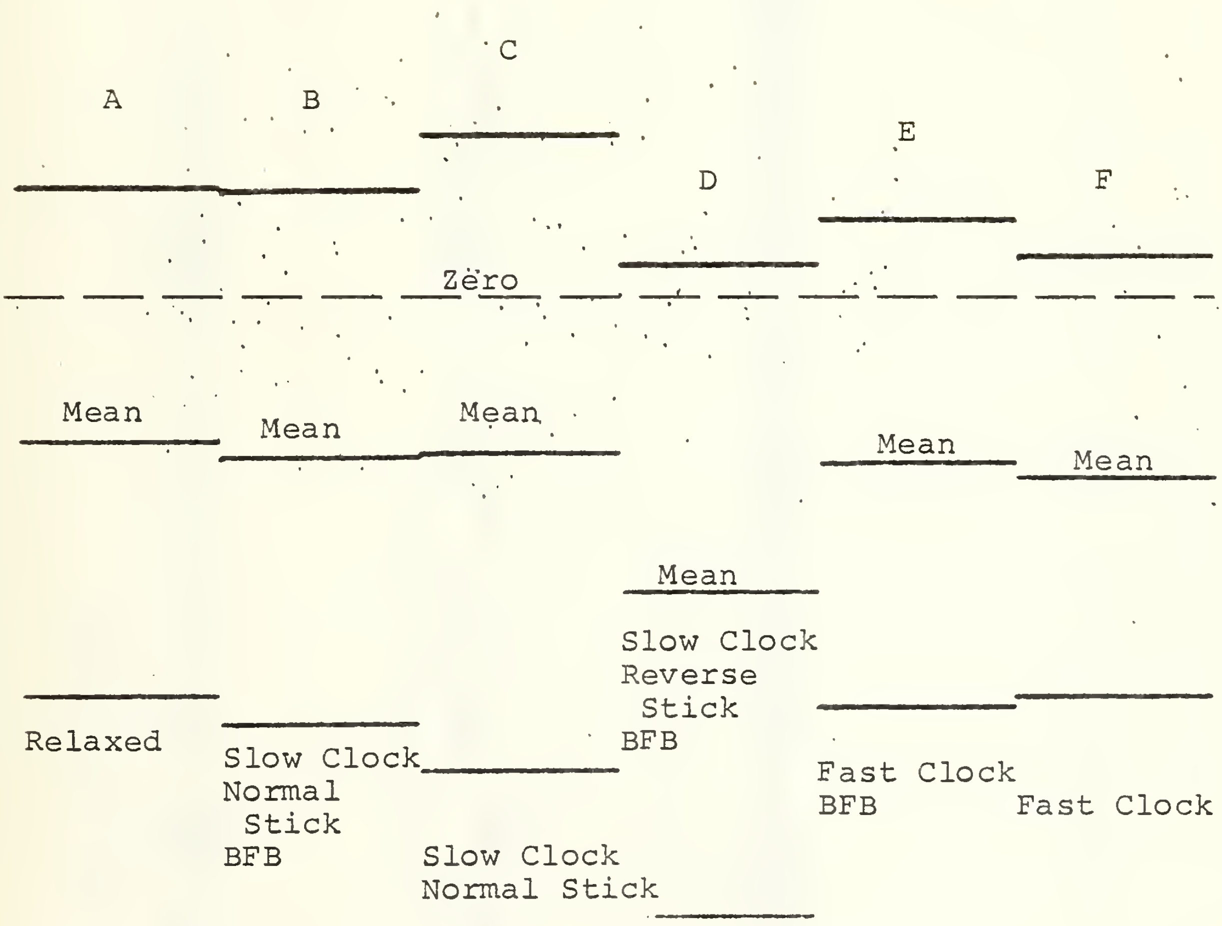


Figure 25. Stress Correlation Plot

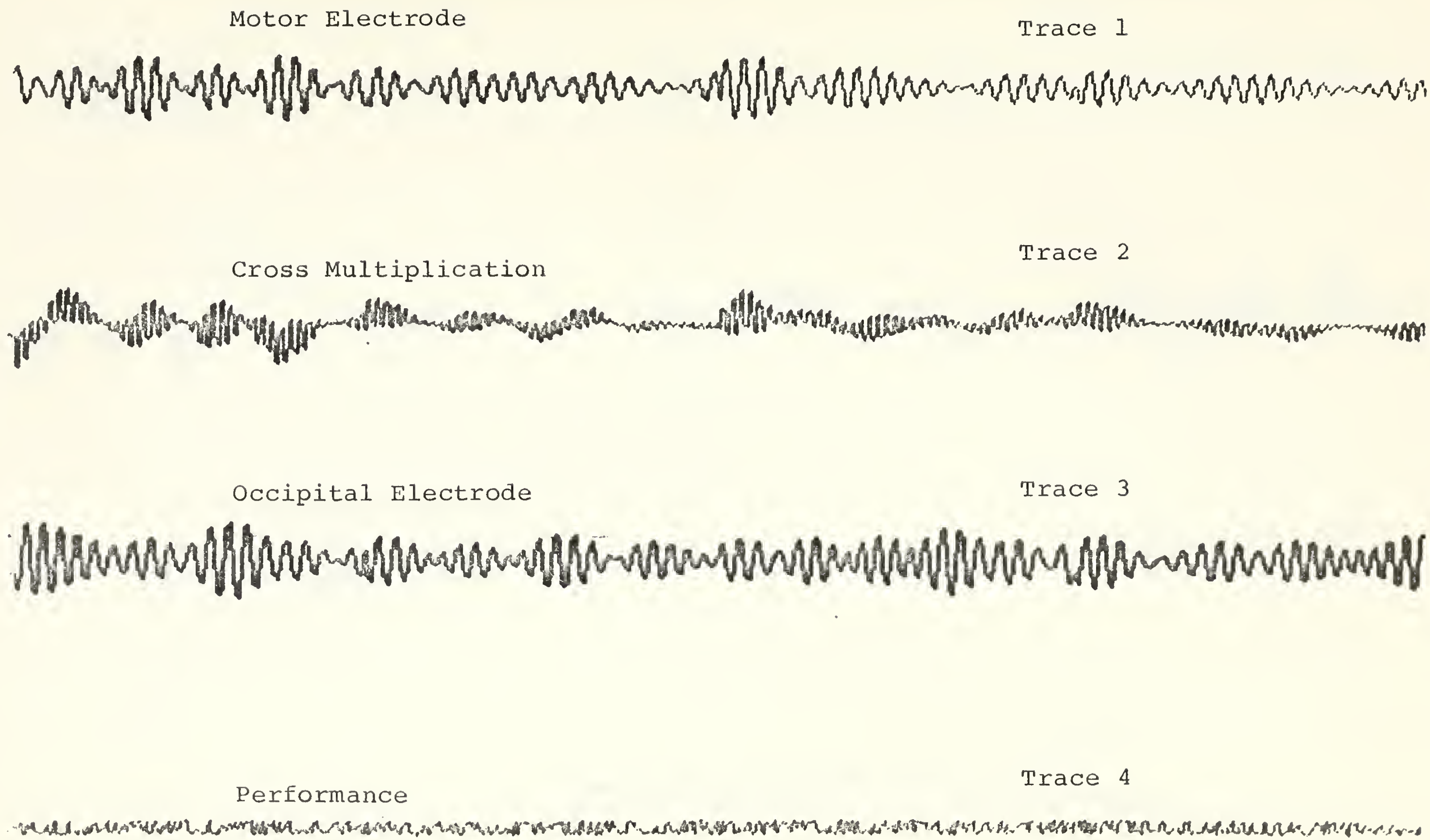


Figure 26. Motor-Occipital: Relaxed, No Stress Plot

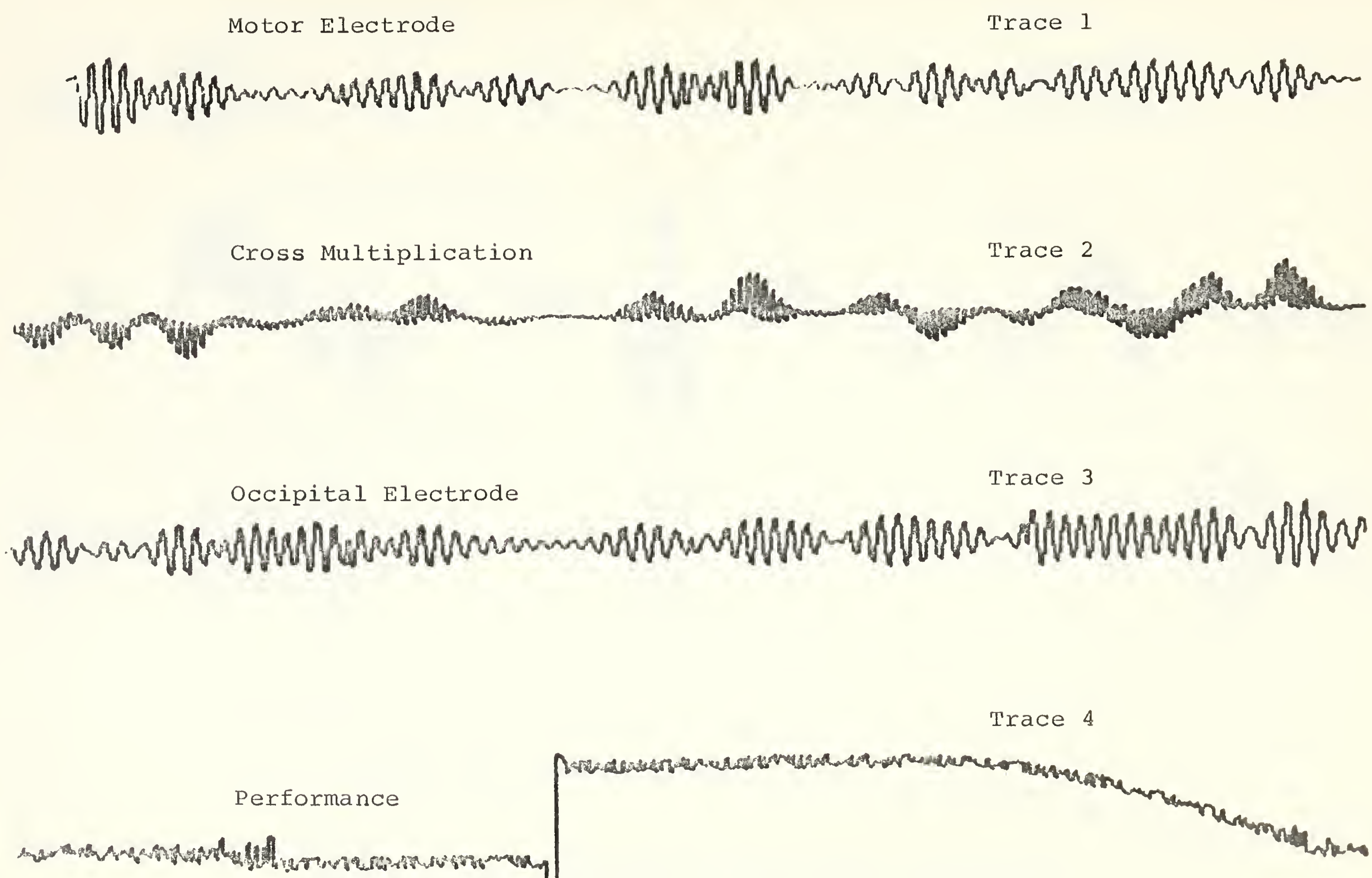


Figure 27. Motor-Occipital: Slow Clock, No Stress

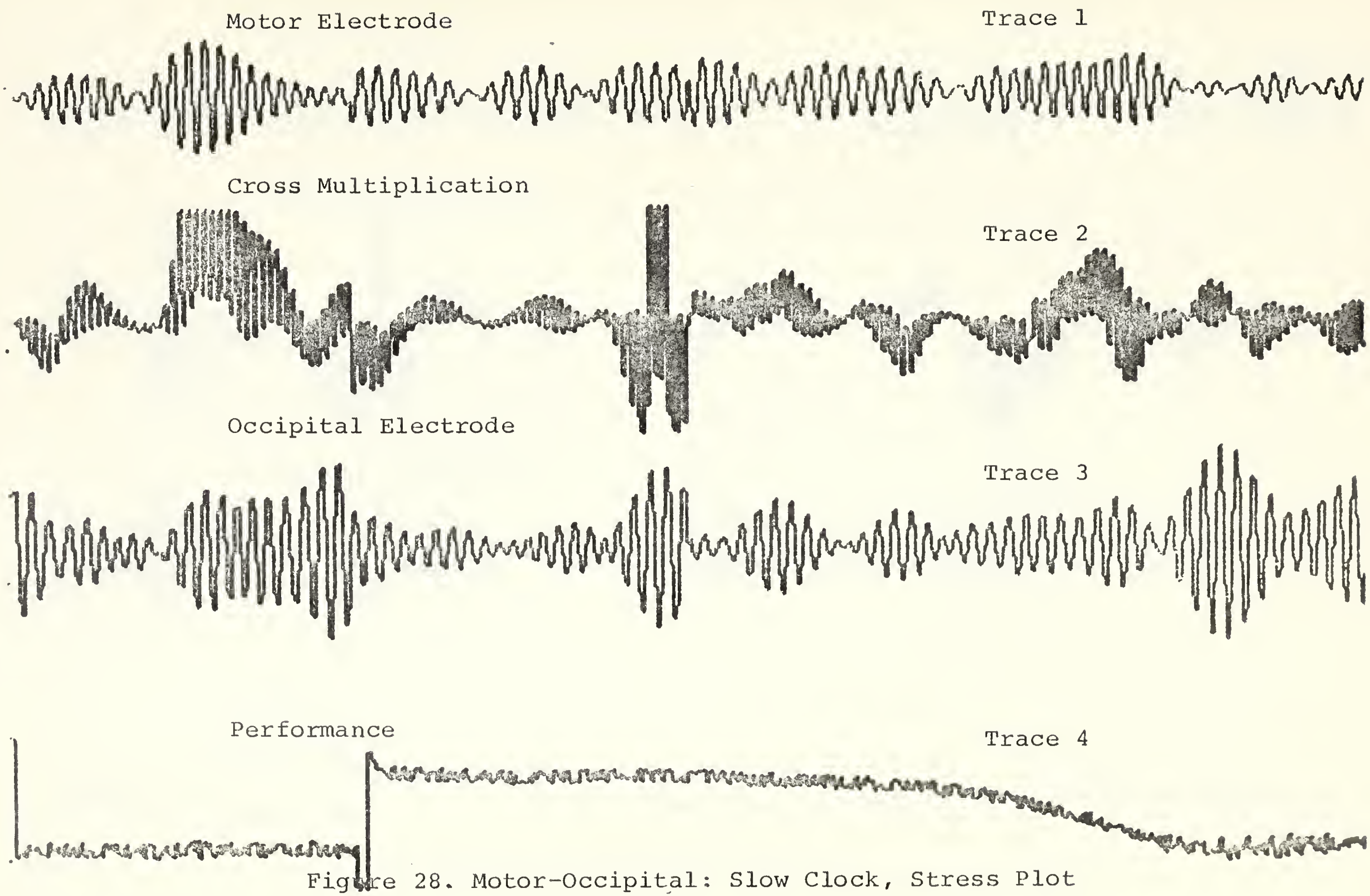


Figure 28. Motor-Occipital: Slow Clock, Stress Plot

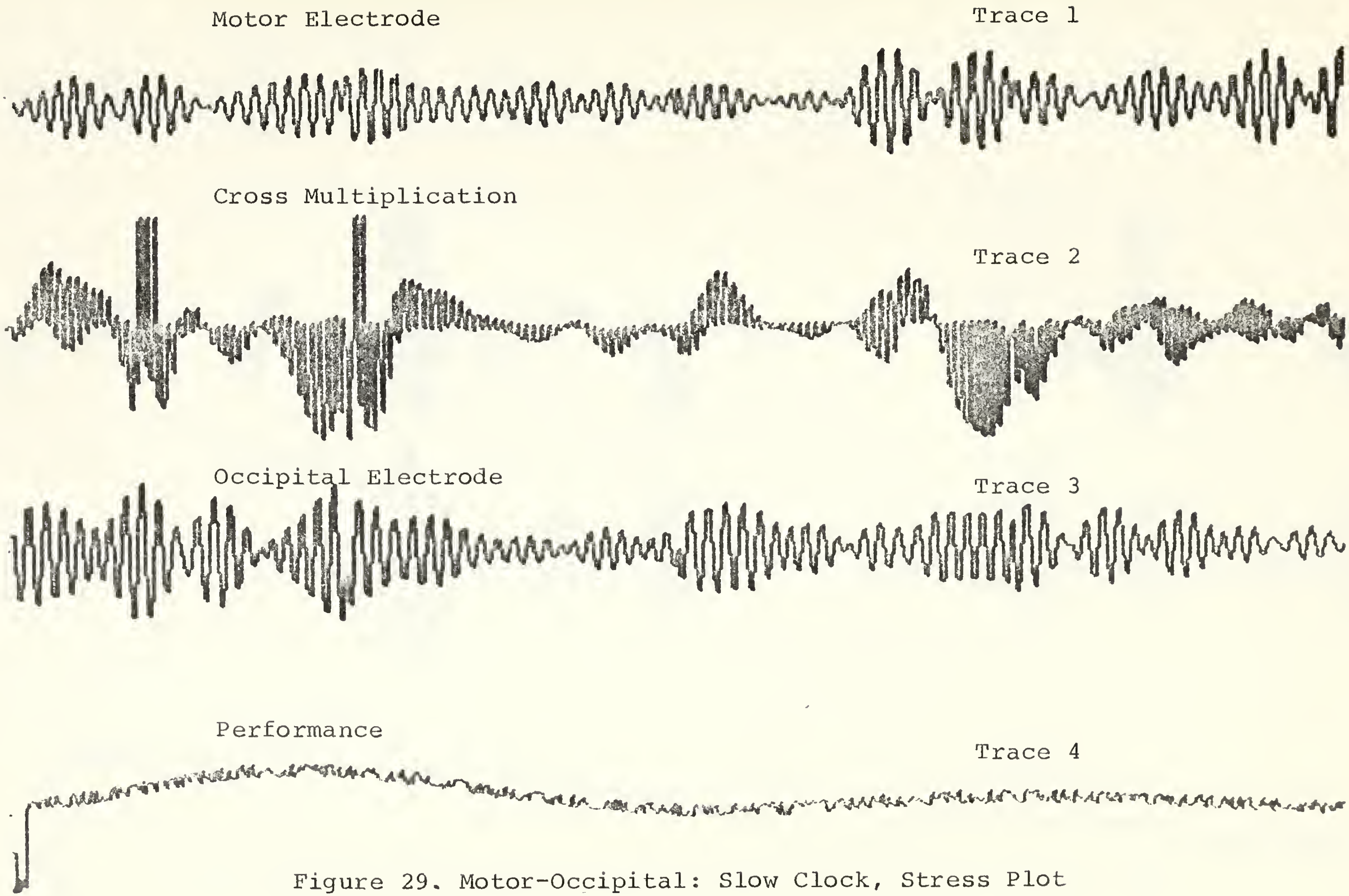


Figure 29. Motor-Occipital: Slow Clock, Stress Plot

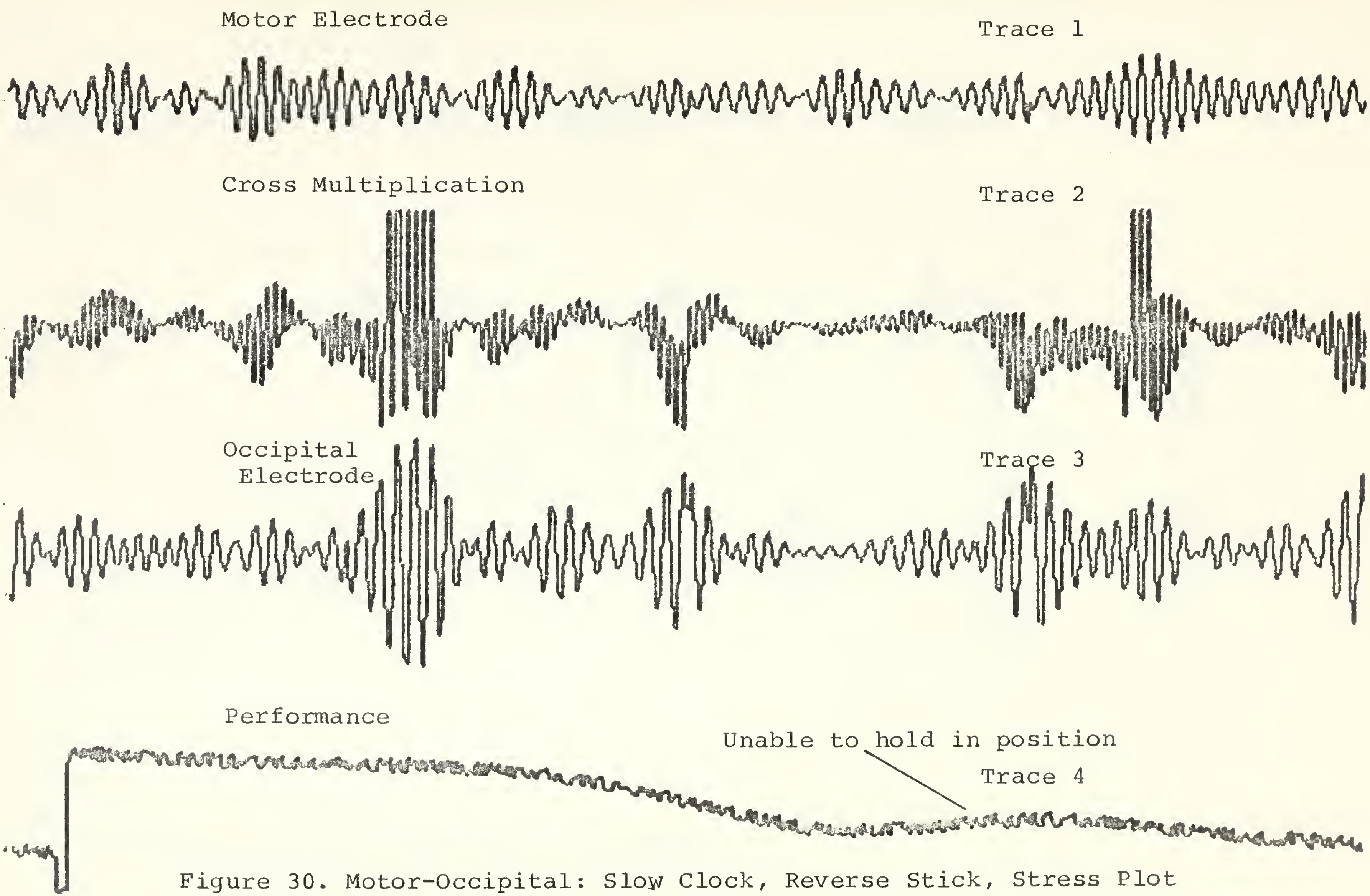


Figure 30. Motor-Occipital: Slow Clock, Reverse Stick, Stress Plot

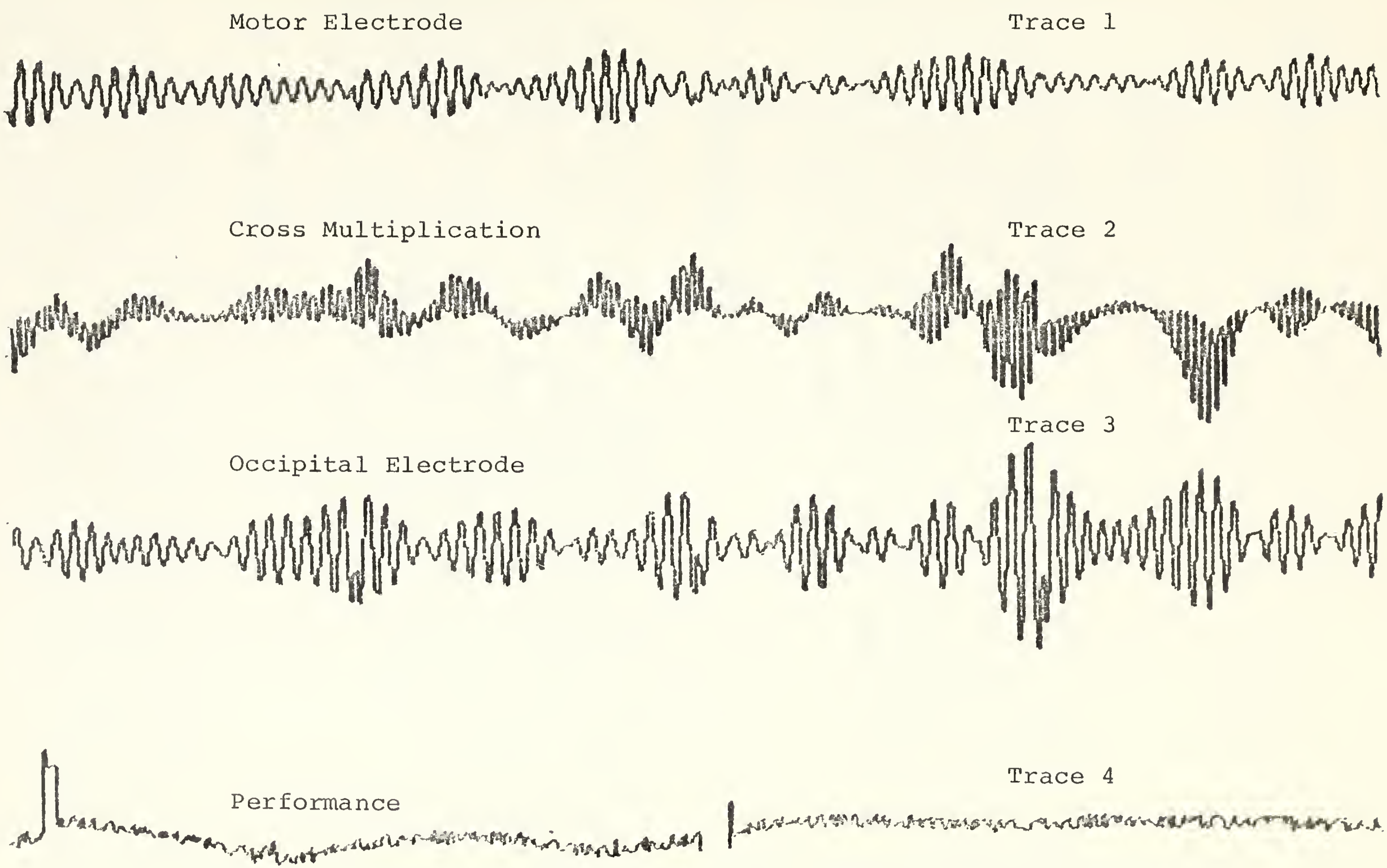


Figure 31. Motor-Occipital: Slow Clock, Reverse Stick, Stress Plot

E. MOTOR-MOTOR RUN

1. General

A final electrode placement was tried with electrodes placed on the left and right motor areas of the brain. As with the motor-occipital run, two runs were actually recorded- first without stress, then with stress. Since the left arm was receiving the electric shock, it was thought that the right motor area might show more activity. Such was not the case, however.

2. Correlation Plot

Figure 32 is the correlation plot for the run without stress and Fig 33 is with stress. In every case, correlation was lower in magnitude with stress, but not as significantly as was observed with the motor-premotor electrode arrangement. It is interesting to speculate that perhaps the large negative correlation without stress indicated communication, without delay, between corresponding right and left motor areas.

3. TWODET Data

Figures 34 and 35 again display the large tegules and trace 2 peaks, but these were exceptional. The majority of the data did not contain these large peaks and this electrode arrangement was therefore not used in additional runs.

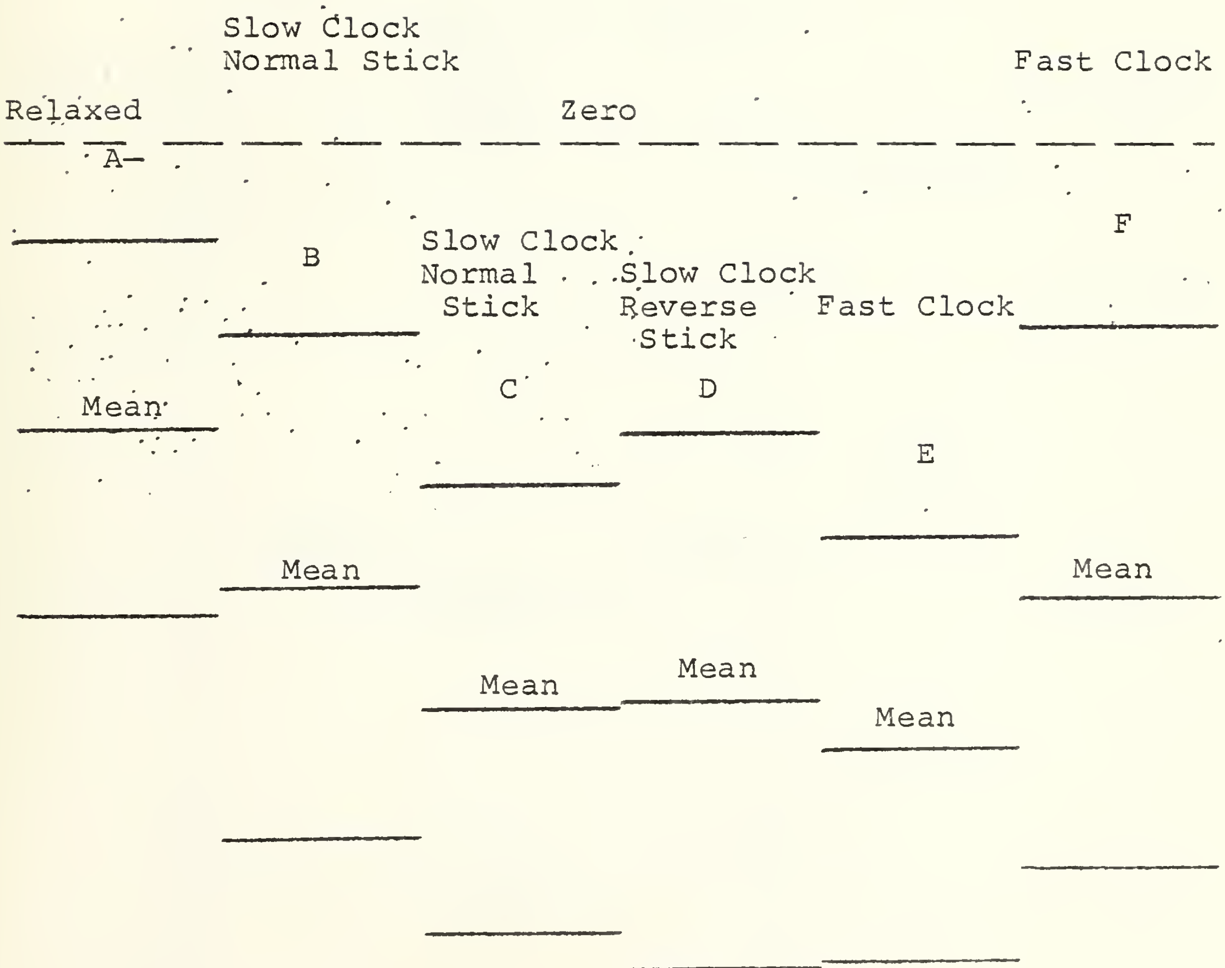


Figure 32.--Motor-Motor No Stress Correlation

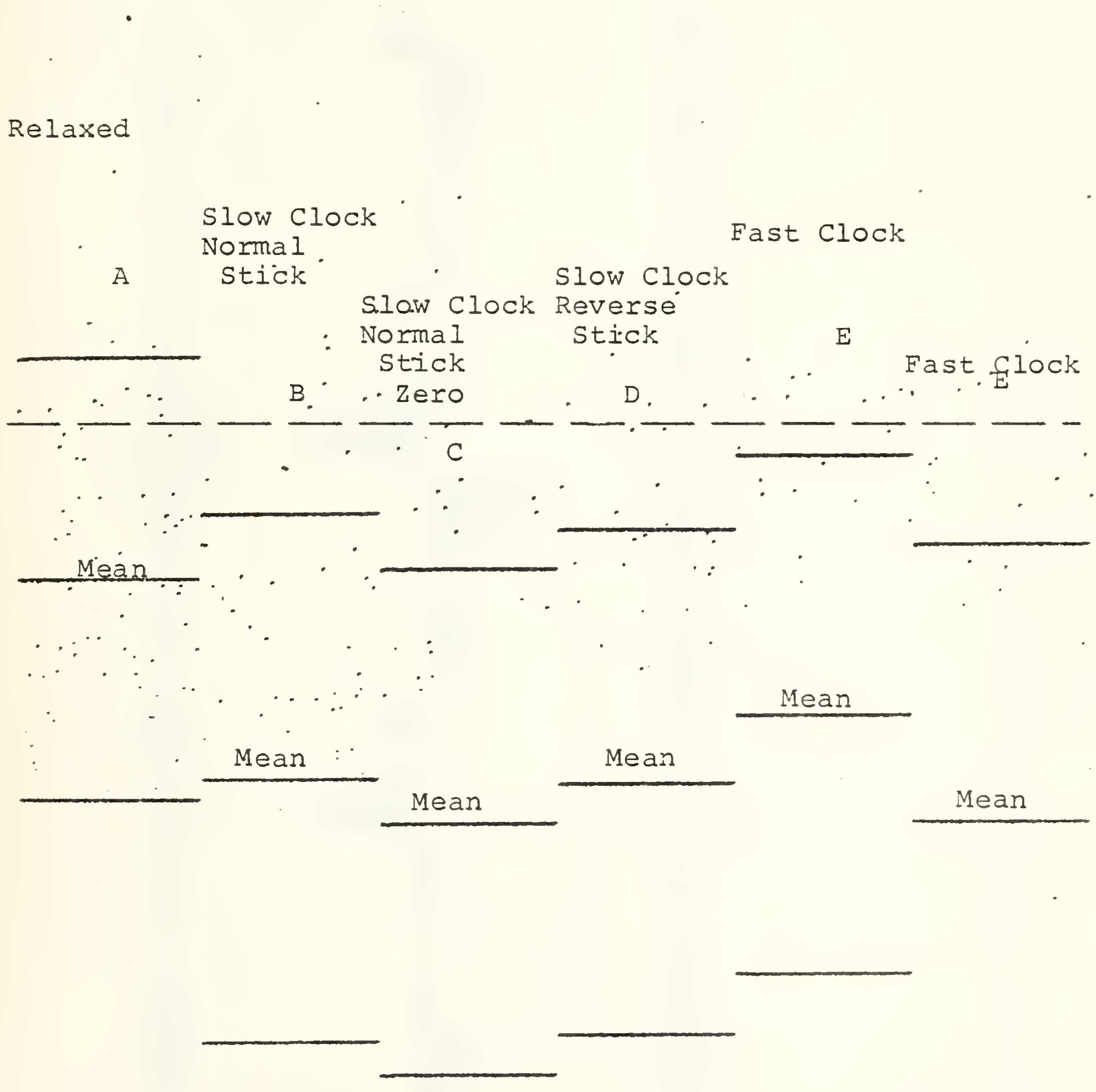


Figure 33. Motor-Motor Stress Correlation Ploy

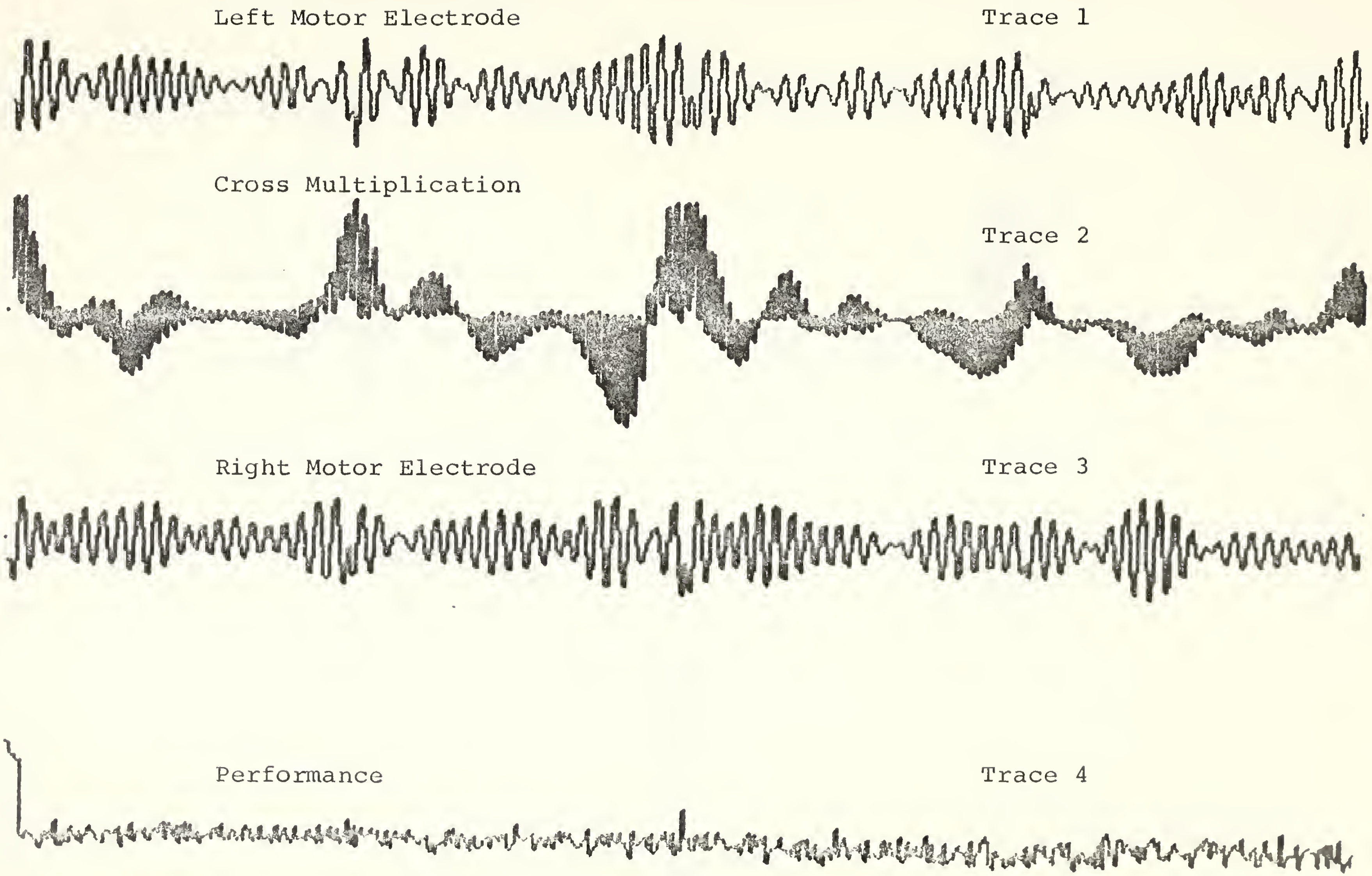


Figure 34. Motor-Motor Stress Plot

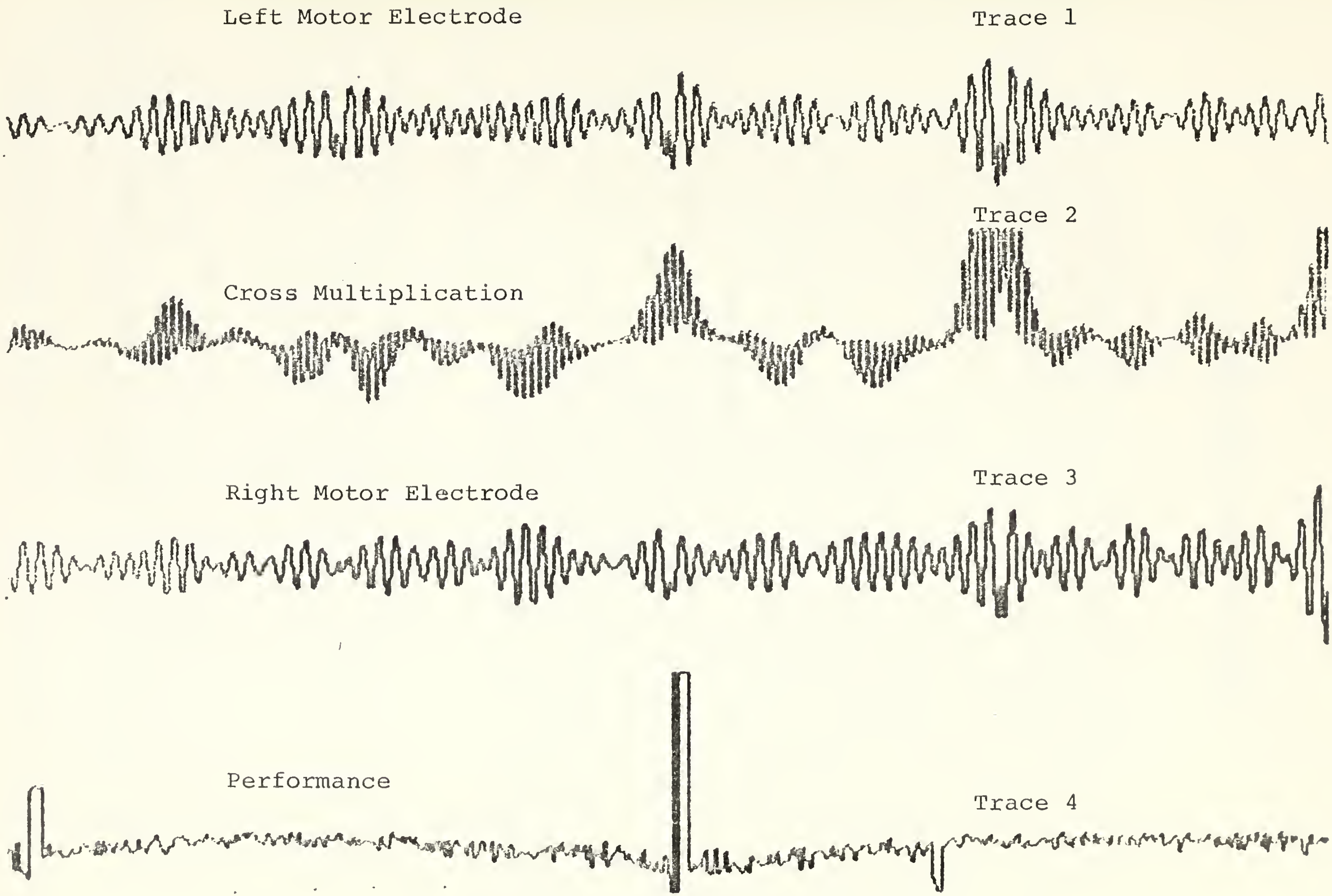


Figure 35. Motor-Motor Stress Plot

VIII. DISCUSSION AND CONCLUSIONS

When attempting to conduct an EEG analysis there are so many variables to be considered that only very careful and elaborate laboratory procedures are permissible if any meaningful and reproducible data is to be collected. A major effort is expended in this laboratory in just such care, and laboratory procedures utilized are the result of much time, effort, and experience of many people. Controlled procedures and reproducibility were considered to be of primary importance while maintaining an open mind about all possibilities. Much of the publicized literature on EEG research is very narrow in scope and some of it, through omission, infers invalid conclusions. Exemplary is the never-ending work at frequencies below 20 Hz, which is marvelously narrow in scope. Reference 7, however, states that significant activity exists well above 50 Hz. All data presented by the author was recorded in the 70-95 Hz band which represents the "preferred frequency" while performing skilled motor tasks.

Data gathered indicates that detection of stress utilizing the EEG is indeed possible. Moreover, there are four indicators of the presence of stress, but not all four are necessarily applicable to each subject.

The first stress indicator is the larger sized tegules on the recorded traces of brain activity. In every case recorded, comparison with non-stress recordings showed these stress traces to be larger and more defined in appearance.

The second stress indicator is the presence of large

peaks on the cross multiplication trace. These are considered significant because they indicate a close coincidence of tegules either in phase or 180 degrees out of phase.

The third indicator is the observation of differing magnitudes of correlation means. The differences are not necessarily in the same direction from one subject to another or one electrode placement to another, but differences do exist.

The fourth stress indicator is the measurement of performance. A trained subject eventually reaches a peak of performance and with some tolerance will normally achieve that same level of performance. However, with the inducement of stress, the performance is consistently deteriorated. This was demonstrated in the last set of data when the subject had voiced the opinion of not having been stressed. The fact that performance was degraded demonstrated that the stress tactics employed were effective.

A comparison of Biofeedback (BFB) in stressful situations seemed to show that performance was enhanced with BFB in these stress runs and was enhanced more dramatically than in non-stressful runs.

Generally speaking, the task related response signature discussed in Ref 4 was either eradicated or masked by stress response, and this may be an indication of stress regardless of amplitudes.

Electrode placement and frequency band may be critical in stress detection. Certainly, electrode placement is important. It is possible that future work may show stress indicators in frequency bands other than 70-95 Hz.

IX. RECOMMENDATIONS FOR FUTURE RESEARCH

If more research is conducted on stress detection utilizing the EEG, there are a number of primary areas which should be investigated. First of these is frequency because there may well be other frequency responses which are indicative of stress, and may even be frequencies peculiar to various types of stress such as mental and physical.

Other electrode locations might prove superior in stress detection, particularly since some areas of the brain may be affected more than others by stress.

Further investigation of the motor-premotor electrode placement in a search for stress patterns may also prove interesting, although the author was unsuccessful in discerning even a continuity of indicators-much less a pattern.

Finally, the possible enhancement of performance under stress by Biofeedback is a most interesting area to investigate.

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